STUDY ON MARSHALL STABILITY OF ASPHALT CONCRETE MIXTURE DUE TO THE ADDITION OF POLYETHYLENE TEREPHTHALATE (PET)

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Abstract. Rapid population growth is directly proportional to the increase in the consumption of polymers or plastics. It is very difficult to decompose in the soil, efforts to use it as an additional material for road construction are important. The addition of polymer can increase the stiffness of the asphalt so that it will improve the quality of the pavement against rutting. [4][5]. The purpose of this study is to determine the effect of adding plastic waste Poly Ethylene Terephalate (PET) mineral plastic bottles to stability of Asphalt Concrete – Wearing Course (AC-WC) mixture using 60/70 penetration asphalt, and to analyze the microscopic structure of the results of Scanning Electron Microscopy (SEM) and Energy Dispersive Spectroscopy (EDS) tests. From the Marshall test, it is known that the stability of the mixture in each variation of the addition of PET meets the required specifications of a minimum of 1000 kg. The highest average stability of 1855.7 kg in all variations of asphalt content was recorded of PET 1.25% of the asphalt weight, which increase the ability of the asphalt mixture of 39% to carry loads. Meanwhile, the smallest stability increase of 3% occurred in the addition of 0.5% PET into asphalt. Through the SEM test, it was seen that there were so many lumps with a larger structure size as a result of the reaction between the asphalt mixture and PET. This agglomeration becomes a structure that is stronger in carrying Marshall loads as detected at a higher stability value of the mixture.

Keywords: Polymer, Plastic, AC-WC, and PET

I. INTRODUCTION

1.1 Background

The recent increase in traffic volume, especially with insufficient funds prepared for road construction maintenance, will accelerate road damage. For this reason, a number of efforts are needed, among others, by maintaining roads so that their quality returns to increase, and improving the design of road pavements. One way to prevent premature damage to road pavement due to loading and the influence of water is to improve the quality of asphalt through the use of additives added to the aggregate binder, such as polymers, plastics, and charcoal. The binder with additive substitution is known as modified asphalt [13].

The recent increase in traffic volume, especially with insufficient funds prepared for road construction maintenance, will accelerate road damage. For this reason, a number of efforts are needed, among others, by maintaining roads so that their quality returns to increase, and improving the design of road pavements. One of the paved road constructions is the backbone of an area in distributing the passenger load of goods and services, besides that the road is also part of the infrastructure to open up isolated areas; for national defense and for social level development; the economy and culture of an area, so that the construction of the road must be strong and resistant to the load of traffic that passes by every day. The addition of polymer can increase the stiffness of the asphalt mixture. Increased stiffness will improve the quality of the pavement against rutting, especially in summer with high temperatures [4][5].

Asphalt Concrete Layer is a layer on highway flexible pavement construction, which consists of a mixture of hard asphalt and aggregate which is continuously graded, mixed, spread, and compressed in a hot state at a certain temperature. The mechanical strength of this mixture is obtained from friction (internal friction) which is influenced by the physical properties of the aggregate, both in grain shape and surface texture (rock roughness) so that the stability value is high. To increase the quality of the mixture, one way is to add additives. Additive is an additional component outside the main component in asphalt concrete that is mixed so that it can have a positive influence on it. Plastic packaging used to store luggage is common nowadays, so that a lot of plastic waste is wasted and not used, this will add to the burden on the government in recycling these inorganic materials.

In this study, plastic bottle waste will be used as an added material to the asphalt concrete mixture. The use of plastic as an alternative additive is expected to improve the quality of asphalt concrete pavement which can be read through the Marshall characteristics of the mixture which include: a. Mixed density (density); b. Value of the percentage of voids in the mixture (VIM); c. The value of the percentage of voids in the mixture filled with asphalt (Void Filled With Asphalt); d. Stability value; e. Melting (Flow); and f. Results for Marshall (Marshall Quotient).

1.2 Aims and Objectives

The objectives to be achieved from this research are:

1. To determine the effect of adding Poly Ethylene Terephalate (PET) plastic waste to the stability test characteristics of the Asphalt Concrete – Wearing Course (AC-WC) mixture using asphalt with a penetration of 60/70.
2. To determine the microscopic structure of the Asphalt Concrete – Wearing Course (AC-WC) mixture using PET plastic waste through Scanning Electron Microscopy (SEM) and Energy Dispersive Spectroscopy (EDS) tests.

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II. COLLECTING AND TESTING OF AGGREGATE MATERIAL

2.1 Study site and design

This research was conducted at the Transportation and Highway Laboratory of Tadulako University. The coarse aggregate, fine aggregate, and fly ash used were taken from the processed stone crusher of Ex Watusampu, Ulujadi District, Palu City which was stocked to AMP PT. Sapta Unggul. Meanwhile, the filler mineral comes from the sands of the Palu river.

Fig.1. Location of Aggregate Collection

For the purposes of making specimens in the laboratory, aggregate collection was carried out using a simple random sampling method on the material population in the stockpile of AMP PT. Sapta Unggul, with the intention of being able to represent all existing aggregates. The aggregate material has gone through the process of breaking in the stone crusher. The collection is carried out using a shovel and several sacks to separate aggregates with different fractions so they are not mixed with one another. Aggregate fractions taken include: 3/4”, 3/8” fraction, rock ash and sand.

Fig.2. Aggregate Material Pick-Up

2.2 Aggregate and Asphalt Specifications Tests

Aggregates play an important role in the performance of asphalt pavement mixes. The amount of aggregated minerals in the mixture is generally 90 to 95 percent by weight and comprises 75 to 85 percent by volume.

Aggregate testing is carried out based on the inspection method of AASHTO, ASTM, BS and method of issued by the Ministry of Public Works, the Directorate General of Highways and also uses the Indonesian National Standard (SNI) inspection method. This test is done to ensure that the technical quality of the aggregate used meets the specifications. Meanwhile, the asphalt used is the type of AC penetration 60/70 produced by PT. Pertamina, which is available at the Highway Transportation Laboratory, Faculty of Engineering, Tadulako University.

The PET in the form of plastic bottles is easy to find because it is widely used in almost every household. Also always used as a beverage packaging material in shopping places such as; shops, supermarkets, markets and so on.

In the following table, the specifications of the aggregate and asphalt tests used in this study are presented.

Table 1. Aggregate and Asphalt Specifications Tests

No.	Item/Unit	Testing Method	Specification	
			Min	Max
Coarse Aggregate				
1.	Gradation/Sieve Analysis	AASHTO T-27	-	-
2.	Absoption (%)	AASHTO T 85	-	3
3.	Bulk Specific gravity Apparent Specific gravity EffectiveSpecific gravity	AASHTO T 85/ASTM C127	2.5	-
4.	Abration (%)	AASHTO T-96/ASTM C131	-	40
5.	Angularity	AASHTO T326/ BS-812	-	-
6.	Soundness	AASHTO T-104/ASTM C88	-	18
Fine Aggregate				
1.	Gradation/Sieve Analysis	AASHTO T-27	-	-
2.	Absoption (%)	AASHTO T 85	-	3
3.	Bulk Specific gravity Apparent Specific gravity EffectiveSpecific gravity	AASHTO T 85/ASTM C127	2.5	-
Filler				
1.	Specific Gravity	AASHTO M-17/ASTM C120	-	-
Asphalt				
1.	Penetration of Bituminous Materials (25°C, 5 sec)	AASHTO T-49	60	79
2.	Softening point (*Ringball*)	ASTM D 36	48	58
3.	Flash and Fire Points by Cleveland Open Cup	AASHTO T-48	200	-
4.	Loosing Weight (163 °C, 5 hr)	AASHTO T-240	-	0,8
5.	**Ductility of Bituminous Materials (25°C, 5 cm/min)**	AASHTO T-51	100	-
6.	Theoretical Maximum Specific Gravity and Density of Bituminous Paving Mixtures(25°C)	AASHT0 T-209/ASTM D 2041	1	-

III. LITERATURE REVIEW

3.1 Polyethilene Perepthalate (PET)

Polyethylene perephthalate which is often called PET with the chemical formula (C10H8O3)n is made from glycol (EG) and terephthalic acid (TPA) or dimethyl ester or perephthalic acid (DMT). PET film is clear, strong, tough, dimensionally stable, flame retardant, non-toxic, low gas, odor and water permeability. PET has low water vapor absorption, as well as water absorption [13].

The use of PET is very wide, among others, for bottles for mineral water, soft drinks, syrup packaging, sauces, jams, cooking oil. Plastic drink bottles circulating in Indonesia are made of Polyethylene Perepthalate (PET), which can be identified by the symbol number 1 on the bottom of the bottle. PET has a specific gravity of 1.38 g/cm3 (20^0C), a melting point of 250^0C, a boiling point of 350^0C (decomposed), a modulus of elasticity of 2800-3100 MPa, and a tensile strength of 55-75 MPa.

Polyethylene is a transparent, white thermoplastic material that has a melting point varying between 110-137ºC. Generally, Polyethylene is resistant to chemicals. The monomer, ethane, is obtained from the cracking of oil or natural gas. [8] conducted a study entitled The Effect of Using Waste Plastic Bottles as Additives on the Characteristics of Asphalt Concrete. From the results of the study, it can be seen that plastic waste from drinking bottles such as PET is useful as an added material in the Asphalt Concrete (Laston) mixture layer, including the stability value of the mixture tends to increase.

The use of Polyethylene of about 6-18% by weight of the optimal asphalt content can reduce deformation of the pavement and can increase fatigue resistance while at the same time increasing the adhesion between asphalt and aggregate [11].

3.2 Paved Mix Volumetric

The asphalt mixture consists of three main components: the aggregate, the binder and the air voids between the aggregates. It is important to maintain the VMA value of the mixture which is a combination of air voids and the asphalt content. Some researchers set the VMA value based on the maximum size of the aggregate, where if the maximum is 19 mm then the VMA is around 14%, while if the maximum is 12.5 mm, the VMA is around 13% [4][5].

Emphasis is placed on volume proportions and two important parameters that need to be defined in order to make it possible to evaluate the mechanical properties of the mixture as important in the design of the mixture, namely:

VB = Proportion of binders by volume, and
VMA = VB + Vv, cavity in mixture

In [2], if the binder content (MB) in units of weight and the cavity content of the mixture are known, then VB can be calculated using the formula:

$$V_B = \frac{(100-V_V)(M_B/G_b)}{(M_B/G_b)+(M_A/G_a)} \quad \text{......(1)}$$

If the variations of aggregate used have different specific gravity, then the effective specific gravity of the Gse aggregate mixture is calculated using the following formula:

$$GSe = \frac{100}{(X/G_X)+(Y/G_Y)+\cdots} \quad \text{......(2)}$$

where X, Y, and so on are weight percentages of each constituent aggregate fraction, with specific gravity of each Gx, Gy, and so on.

Some designers combine VMA, air voids, and experience to determine the best asphalt content. Some other planners use an approach by combining air voids, surface area and film thickness, and experience to determine the best asphalt content [9].

3.3 Combined Aggregate Gradation

The gradation or distribution of particles based on the size of the aggregate will determine the size of the voids between grains, the stability and performance of the pavement. [10] reported that in determining the composition of the asphalt mixture using the by portion method by trial and error. starting with filtering each aggregate fraction using a set of sieves according to specifications, after the % data passes each size is known, then the aggregate composition is made and the results are compared with the required gradations. In the performance-based HMA mix specification, fundamental to this specification is the gradation requirement using black areas, i.e. zones of prohibition developed to prevent the acquisition of asphalt mixtures that are soft and susceptible to deformation. [3], [7], [8], and [11].

Mix design is intended as an effort to determine the optimum gradation of aggregate and asphalt content in the asphalt mixture, taking into account the gradation requirements and the target air voids to be achieved. The asphalt content in the mixture ranges from 4% - **7%.** The initial estimate of the optimum asphalt content can be obtained using the following empirical formula:

Pb = 0.035 (%CA) + (0.045 (%FA)) + 0.18 (% Filler) + C ....(3)

where: Pb = Asphalt Content, CA = Coarse Aggregate, FA = Fine Aggregate.

The constant value (C) is about 0.5 – 1.0 for asphalt concrete, and 2.0 – 3.0 for HRS. The value of C depends on the type of mixture, for Asphalt Concrete the C value is 0.5% - 1%.

3.4 Plastic Waste as Additive for Mixed Asphalt AC-WC

Polymer asphalt modifications have been developed over the last few decades. Generally, with a little addition of polymer material (between 2-6%) it can increase the results of better resistance to deformation, overcome cracks and increase high resistance to age damage so that road construction is more durable and can reduce maintenance costs or reduce costs. road repair [15].

The use of plastic packaging cannot be separated in everyday life. This is because plastic has superior properties such as light but strong, transparent, waterproof, and the price is relatively cheap and affordable by all people [17]. Additives have liquid or solid properties, because PET has inelastic and thermoplastic properties, namely at high temperatures it will melt but at ambient temperature it will become hard [2].

3.5 Scanning Electron Microscope (SEM) Testing

SEM is a type of electron microscope that describes a specimen by scanning it using a high-energy electron beam in a raster pattern scan. The electrons interact with the atoms so that the specimen produces a signal that contains information about the specimen's surface topography, composition, and other characteristics such as electrical conductivity.

The types of signals generated by SEM include secondary electrons, back-scattered electrons (BSE), X-ray characteristics, light has a detector that can read all signals. This signal is the result of the interaction of the electron beam with atoms near the surface of the specimen. The most common or standard mode of detection, secondary electron imaging (SEI), SEM can produce very high-resolution images of the specimen surface, resulting in a size of less than 1 nm in detail. Because the electron beam is very narrow, the SEM image has a depth that can produce a characteristic three-dimensional appearance that is useful for understanding the surface structure of a specimen.

SEM allows multiple magnifications, from about 10 times (about the equivalent of a hand lens) to over 500,000 times magnification, or about 250 times the magnification capability of an optical microscope. The scattering electron (BSE) is a beam of electrons reflected from the specimen by elastic scattering. BSE is often used in SEM analysis along with spectra made of characteristic X-rays. Since the intensity of the BSE signal is strongly related to the atomic number (Z) of the specimen, BSE images can provide information about the distribution of different elements in the specimen. For the same reason, BSE imaging can depict immuno gold colloidal labels that are 5 or 10 nm in diameter, making it difficult or impossible to detect secondary electrons in biological specimen images. Characteristic X-rays are emitted when the electron beam removes the inner shell electrons from the specimen, causing the higher energy electrons to fill the shells and release energy. These X-ray characteristics are used to identify the composition and measure the abundance of elements in the specimen.

IV. RESEARCH METHODOLOGY

In order for the research to be more focused, each activity is arranged according to the order as in the flow chart in Figure 4.

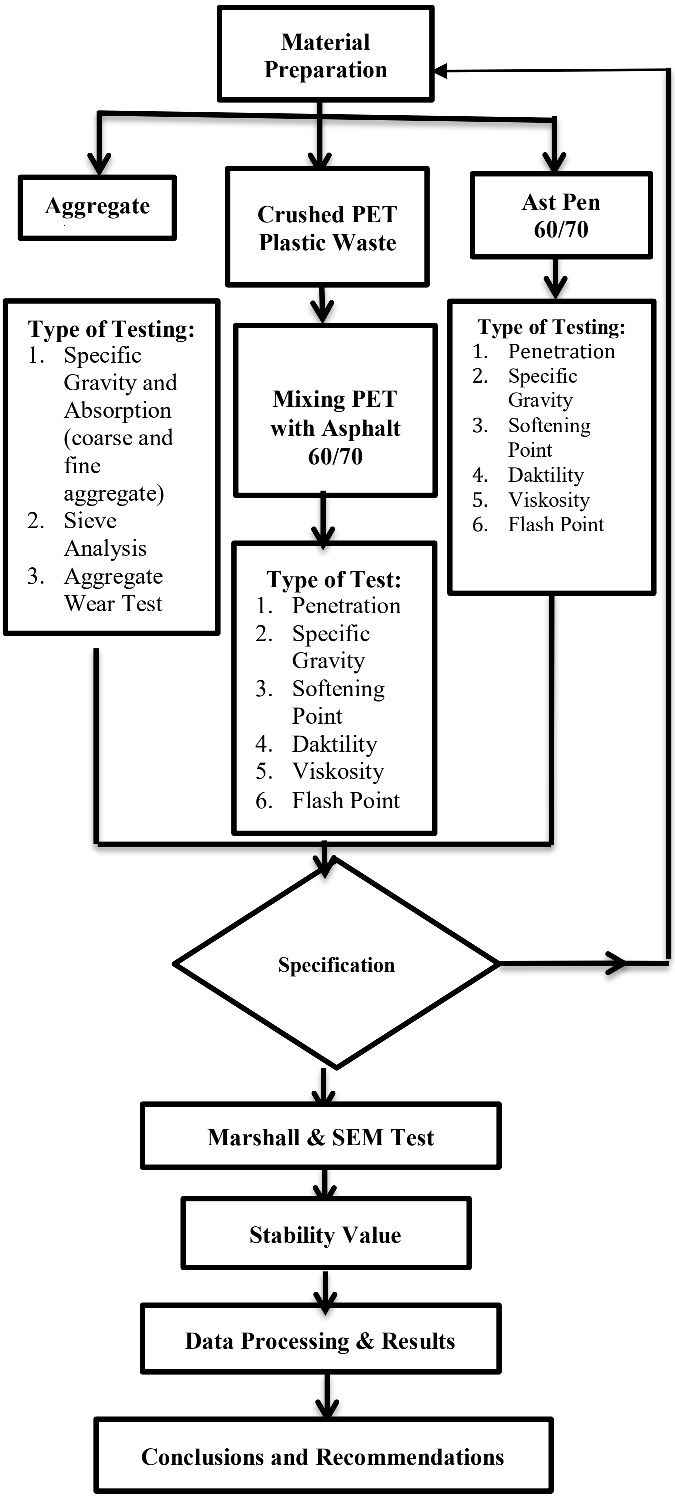

Fig.4. Sequence of Research Activities

4.1 PET Waste Collection and Treatment

The collection of PET plastic waste is quite simple, the collection is only done randomly at the final disposal site (TPA) and sorted according to the needs of the use of the waste. The PET taken is a mineral bottle of Aqua brand. In taking the sample, it is necessary to pay attention to:

1. After the plastic waste sample is obtained, it is washed first using detergent soap. It aims to remove the oil content or other substances in the bottle that can affect when mixed with asphalt.
2. After washing, the plastic waste is dried in the sun to remove the water attached to the plastic waste.
3. Cut PET plastic waste with a width of 1-2 cm to make it easier during the crushing process.
4. After that the waste is ready to be processed into the crushing machine.

Processing of PET plastic waste material obtained from the TPA is carried out by using a grinding machine or plastic waste crusher. The steps are as follows:

1. Cut the plastic with a size between 1-2 cm to facilitate the process of destroying the plastic waste.
2. Pour into the funnel of the grinding machine little by little so that the grinding process does not get jammed when the crusher rotates.
3. When the grinding machine starts to crush, what needs to be paid attention to is the piece of plastic in the funnel that has not been milled so that it is directed or pushed into the crushing eye with a tool in the form of a stick of wood to speed up the crushing process.
4. After the destruction process is complete, clean the tool so that when it will be used again it does not get stuck or does not rotate due to the presence of plastic pieces attached to the grinding machine.

Fig.5. PET Plastic Waste Shredder Machine

Table 2. Number of Samples at Each PET Level

PET percentage (%)	Number of Test Samples								
	Asphalt Content Variations (%)					Marshall Leftover Marinade (60^0C)			
						With PET		Without PET	
	A	B	C	D	E	30 mnts	24 hours	30 mnts	24 hours

PET percentage (%)	Number of Test Samples								
	Asphalt Content Variations (%)					Marshall Leftover Marinade (60^0C)			
						With PET		Without PET	
	A	B	C	D	E	30 mnts	24 hours	30 mnts	24 hours
0	3	3	3	3	3	3	3	3	3
0,25	3	3	3	3	3	3	3		
0,50	3	3	3	3	3	3	3		
0,75	3	3	3	3	3	3	3		
1	3	3	3	3	3	3	3		
1,25	3	3	3	3	3	3	3		
Sub Total	18	18	18	18	18	18	18	3	3
Total	132								

4.2 Research Locations and Testing Materials

The research will be conducted at the Transportation and Highway Laboratory, Faculty of Engineering, Tadulako University.

The materials used in the study were aggregate (coarse and fine) and rock ash originating from Ex Watusampu, Ulujadi District, Palu City, which were stocked at AMP PT. Sapta Unggul, as a result of the production of a stone crusher owned by the company. The mineral filler is taken from the sand of the Palu River, while the filler used is Semen Tonasa. The collection of crushed stone aggregate fraction was carried out at three stockpile points with different grain sizes, namely the fraction 3/4", 3/8", and rock ash. The collection is carried out using a shovel or hoe and then put into different sacks according to the type of fraction to be taken.

PET in the form of plastic bottles is easy to find because it is widely used in almost every household. Also always used as a beverage packaging material in shopping places such as; shops, supermarkets, markets and so on.

4.3 Analysis Method

To determine the performance of the AC WC asphalt mixture using stone crusher material, the following analytical method is needed;

1) Aggregate Technical Quality Test which includes testing of coarse aggregate, fine aggregate, dust, sand and asphalt binder according to specifications.
2) Testing the mechanical properties of the material, namely the hardness which shows its resistance to plastic deformation. Coarse aggregate mechanical testing was carried out by Abrasion Test using the Los Angelos Machine.
3) Mechanical Testing of Mixed Aggregate Base Layers (LPA) includes; sieving analysis test, compaction test (modified proctor test) and CBR test.
4) Asphalt Mixture Characteristics Testing. This test aims to determine the fundamental properties of the mixture.

V. RESULTS AND DISCUSSION

5.1 Low-Density Polyethylene (LDPE)

The results of testing for specific gravity and aggregate absorption are in accordance with the test methods required by SNI 1969:2008 for coarse aggregates and SNI 1970:2008 for fine aggregates, presented in Table 3.

Table 3. Number of Samples at Each LDPE Level

No.	Testing Type	Specification	Result	Unit	Explanation
	Coarse Aggregate				
1.	Bulk specific gravity	> 2,5	2,783	gr/cm3	qualify
2.	Saturated surface dry		2,802		
3.	Apparent specific gravity		2,837		
4.	Absorption	< 3	0,683	%	
	Fine Aggregate				
1.	Bulk specific gravity	> 2,5	2,635	gr/cm3	qualify
2.	Saturated surface dry		2,666		
3.	Apparent specific gravity		2,718		
4.	Absorption	< 3	1,163	%	

5.2 Sieve Analysis Test Results

The sieving analysis test was carried out according to ASTM C136: 2012 with a minimum weight of coarse aggregate for ¾” sieve analysis with a minimum of 5 kg and a minimum weight of coarse aggregate for 3/8” aperture sieving of 1 kg.

Table 4. Results of Aggregate Fraction Sieve Analysis ¾”

Sieve Number	Diameter (mm)	Retained Weight (gr)	Total Percent Passed (%)	
			Retained	Cumulative Pass
Fraction ¾”				
¾”	19	0,00	0,00	100,00
½”	12,5	618,90	29,42	70,58
3/8”	9,5	785,10	66,73	33,27
4	4,75	515,85	91,25	8,75
8	2,36	104,70	96,22	3,78
16	1,18	15,05	96,94	3,06
30	0,6	9,50	97,39	2,61
50	0,3	4,30	97,60	2,40
100	0,15	11,70	98,15	1,85
200	0,075	11,95	98,72	1,28
Pan		26,95	100,00	0,00

In the same way as the ¾" fraction above, data from the sieving analysis for the 3/8" aggregate fraction, sand, rock ash, and filler are also entered in the table, to then be plotted in the form of an orthogonal graph of the relationship between sieve diameter and percent pass. for each aggregate fraction used.

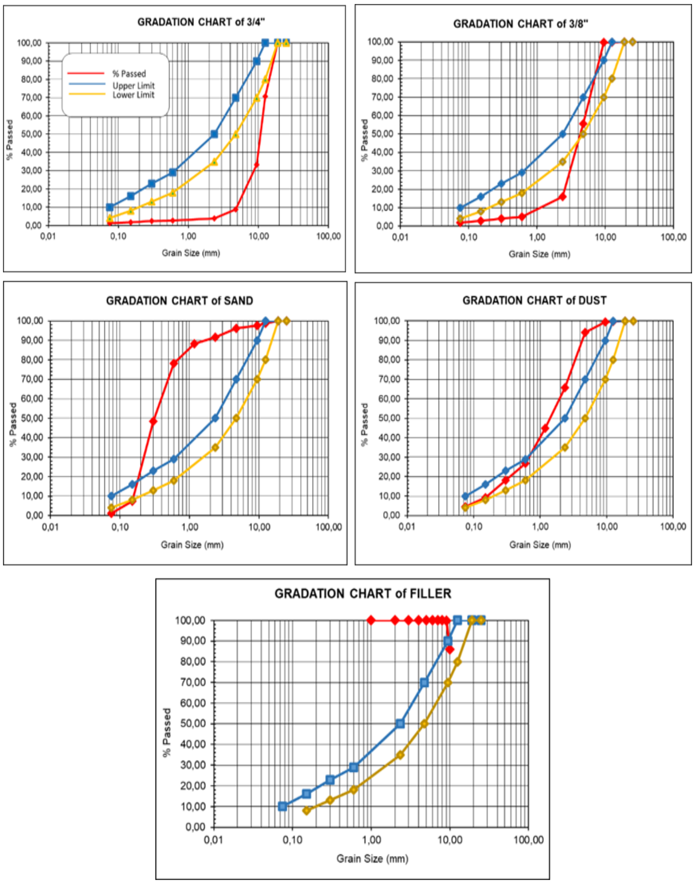

Fig.6. Aggregate Fraction Gradation Graph

5.3 Aggregate Composition in Mixture

The design of the aggregate composition for the asphalt mixture uses the Trial Mix by portion method. The results of the aggregate composition can be seen in Table 5.

The total weight of aggregate required for the manufacture of 1 test object is 1200 and Figure 5 shows the continuous gradation model used in the AC-WC mixture.

From the test results above it can be seen that the aggregate sourced from the Stone Crusher PT. Sapta Unggul meets predetermined specifications, so it can be used in mixtures. From the trial mix to the results of the sieving analysis of the 5 (five) fractions, the mixed aggregate composition was made in such a way that it meets the 2018 Highways Gradation Specifications revision 2.

Table.5. Composition of Combined Aggregate Mixed Laston AC-WC

Sieve Number	Percentage of Each Fraction (%)						Specification
	3/4 " **19**	3/8 " **23**	Dust **47**	Sand **9**	Filler **2**	Total **100.00**	
1 "	19.00	23.00	47.00	9.00	2.00	100.00	100
3/4"	19.00	23.00	47.00	9.00	2.00	100.00	100
1/2"	13.41	22.95	46.93	8.90	2.00	94.19	80 - 100
3/8"	6.32	22.93	46.73	8.78	2.00	86.76	70 -90
#4	1.66	12.77	44.19	8.65	2.00	69.28	50 - 70
#8	0.72	3.71	30.93	8.25	2.00	45.61	35 - 50
#30	0.50	1.15	12.64	7.04	2.00	23.33	18 - 29
#50	0.46	0.96	8.56	4.36	2.00	16.34	13 - 23
#100	0.35	0.65	4.32	0.66	2.00	7.99	8 - 16
#200	0.59	0.44	2.12	0.10	1.72	4.97	4 - 10

From Table 5 above it is recorded that the percentage of each aggregate fraction ¾", 3/8", dust, sand and filler respectively 19%, 23%, 47%, 9%, and 2%. It can be seen that the combined gradation of the five fractions has met the gradation specifications. For more details, it is presented in the form of a gradation chart as shown in Figure 7.

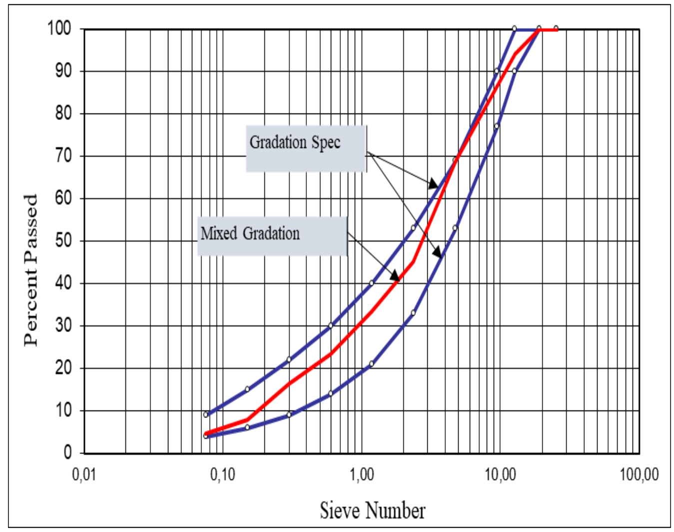

Fig.7. AC-WC Combined Aggregate Gradation Chart

5.4 Abrasion Test Results

The abrasion test was carried out on coarse aggregate of 2500 ± 10 g with a maximum grain size that passed through a sieve of 19 mm (¾ inch) and was retained by a sieve of 12.5 mm (½ inch), and passed through a sieve of 12.5 mm (½ inch) and retained by a sieve of 9 .5 mm (3/8 inch), using Los Angeles Engines. This test is intended to determine the level of wear of the material being tested. The method used is SNI 2417:2008, gradation type B. The results of the abrasion examination can be seen in Table 6.

Table.6. Abrasion Test Results

No.	Test Type	Condition	Result	Unit	Explanation
1.	500 Spin Abrasion	< 30	18,01	%	Qualify

5.5 Asphalt Testing Results

The asphalt used in the AC-WC mixture is Pen 60/70 produced by Pertamina. To find out the quality, a test is carried out according to the characteristic value of the asphalt material. The results of the asphalt characteristic test are presented in Table 6.

Table.7. Asphalt Binder Material Test Results

No.	Test Type	Test Result	Condition	Unit	Explanation
1.	Penetration (25°C, 5 det)	66,60	60 - 70	0,1 mm	
2.	Specific Gravity	1,02	≥ 1,0	-	
3.	Softening Point	48,90	≥ 48	°C	
4.	Daktility (25°C, 5 cm)	109,00	≥ 100	cm	Qualify
5.	Viskosity (135°C)	371,61	≥ 300	cst	
6.	Flash Point	325,50	≥ 232	°C	
7.	Losing Weight	0,059	≤ 0,8	%	

5.6 Asphalt Mixture With Addition of PET

Examination of the physical properties of asphalt added with PET material was carried out as in the Pen 60/70 asphalt test. The PET content added was 0.25%, 0.50%, 0.75%, 1.00% and 1.25% by weight of asphalt.

Table.8. PET Added Asphalt Test Results

No.	Result & Unit	Test Result (%)					Condition	Result
		0,25	0,50	0,75	1,00	1,25		
1.	Penetration (25°C, 5 det)	23,00	22,90	22,50	21,80	19,60	60 - 70	Some do not meet the requirements
2.	Specific Gravity	1,03	2,06	4,34	2,40	2,73	≥ 1,0	
3.	Softening Point	51,80	52,60	52,65	52,75	58,60	≥ 48	
4.	Daktility (25°C, 5 cm)	135,90	131,20	122,15	92,55	39,50	≥ 100	
5.	Viskosity (135°C)	985,97	736,22	1206,62	1121,23	2231	≥ 300	
6.	Flash Point	326,50	327,50	328,50	329,50	330,00	≥ 230	
7.	Losing Weight	0,029	0,028	0,017	0,029	0,029	≤ 0,8	

Based on the data in table 8 above, an estimate of the Optimum Asphalt Content (OAC) can be determined as follows:

FF = 4,97 %
CA = 100 % - (% passed sieve no.8).
= 100 % - 45,61 % = 54,39 %
FA = (% passed sieve no.8) - % Filler
= 45,61 % - 4,97 % = 40,64 %
C = Constant taken 1 (Constant value 0.5 – 1.0 for AC-WC)
So, eOAC = 0,035 (% CA) + 0,045 (% FA) + 0,18 (% FF) + C
= 0,035 (54,39%) + 0,045 (40,64%) + 0,18 (4,97%) + 1
= 5,58% ≈ 6,00%

Once the eOAC is known, variations in the asphalt mixture content can be determined by taking the two asphalt content values that are above and the two asphalt content values below with an interval of 0.5%. Based on the above calculations, the variations in asphalt content are obtained, namely: 5.0%; 5.5%; 6.0 %; 6.5%; and 7%.

The following is the calculation of the proportion of the AC-WC mixture for 5% asphalt content:

The total weight of the test objects = 1200 grams
- Asphalt Weight: 1200 grams x 5% = 60 grams
- Aggregate Weight: 1200 grams – 60 grams = 1140 grams

Aggregate mix proportions
- Fraction ¾ " : 19% x 1140 = 216.6 grams
- Fraction 3/8" : 23% x 1140 = 262.2 grams
- Stone ash : 47% x 1140 = 307.8 grams
- Sand : 9% x 1140 = 102.6 grams
- Cement (filler) : 2% x 1140 = 22.8 grams

Total Aggregate = 1140 grams

In the same way, the required weight of the aggregate fraction mix at each asphalt content can be determined, as shown in the table below.

Table.9. AC-WC Mix Proportions

No.	Sample Weight (gram)	Asphalt Content (%)	Asphalt Weight (gram)	Aggregate Weight (gram)
1.	1200	5.00	60.00	1140.00
2.	1200	5.50	66.00	1134.00
3.	1200	6.00	72.00	1128.00
4.	1200	6.50	78.00	1122.00
5.	1200	7.00	84.00	1116.00

To facilitate the calculation of the weight of each aggregate fraction needed to make 1 test object, it is made in tabular form.

Table.10. Proportion of Mixture and Aggregate Fraction

No.	Aggregate Weight (gr)	Fraction 3/4"	Fraction 3/8"	Dust	Sand	Filler	Total Aggregate (gr)	Total Aggregate + Asphalt (gr)
		19%	23 %	47 %	9 %	2%		
1.	1140	216.60	262.20	535.80	102.60	22.80	1,140	1,200
2.	1134	215.46	260.82	532.98	102.06	22.68	1,134	1,200
3.	1128	214.32	259.44	530.16	101.52	22.56	1,128	1,200
4.	1122	213.18	258.06	527.34	100.98	22.44	1,122	1,200
5.	1116	212.04	256.68	524.52	100.44	22.32	1,116	1,200

5.7 Marshall Test Results

OAC is the asphalt content that meets all Marshall parameters according to the 2018 Bina Marga specifications, namely: Stability, Flow, Marshall Quotient (MQ), Cavities filled with asphalt (VFB), Cavities in the mixture (VIM), and Cavities in aggregate (VMA). Before the Marshall test was carried out, the specimens that had been mixed and compacted were allowed to stand for ± 24 hours, then immersed in a water bath with a temperature of 60°C for 30 minutes. The data read in the marshall test are stability and melting. Then an analysis is performed to determine the value of VIM, VMA, stability, fatigue (Flow), and MQ.

Marshall test results and volumetric analysis of the AC-WC mixture are presented in the following table;

Table.11. Marshall Characteristics of AC-WC Asphalt Mixture

Mixture Properties	Composition of Asphalt in Mixture					Unit	Specification
Asphalt Content	5,0	5,5	6,0	6,5	7,0	%	-
Density	2,37	2,41	2,41	2,42	2,43	gr/cm³	-
VIM	6,46	4,49	3,57	2,36	1,42	%	3 - 5
VMA	16,74	16,05	16,31	16,34	16,59	%	Min. 15
VFB	61,42	72,05	78,15	85,55	91,45	%	Min. 65
Stability	1215,39	1341,54	1403,57	1347,83	1350,76	kg	Min. 800
Flow	3,03	3,17	2,23	2,85	2,98	mm	2 - 4
MQ	399,81	428,85	630,99	476,28	487,57	Kg/mm	Min. 250

From the data in Table 11, a graph of the relationship between asphalt content and the volumetric characteristics of the mixture (density, VIM, VMA, and VFB) is made and a graph of the relationship between asphalt content and Marshall characteristics. While the relationship between asphalt content and Marshall characteristics includes stability, flow, and MQ.

Based on the results of the Marshall and volumetric tests on several variations of asphalt content, OAC was obtained as shown in the image below:

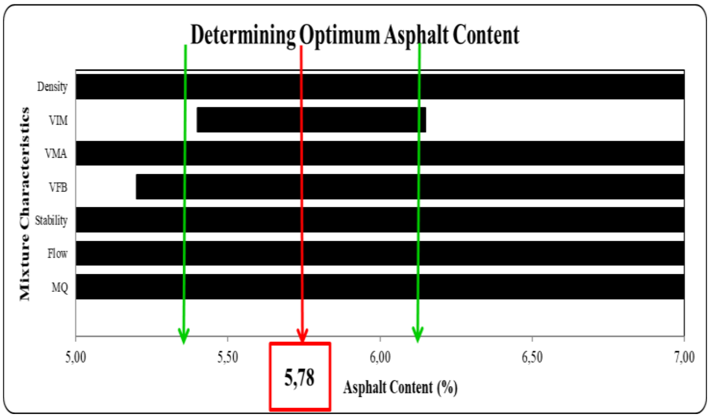

Fig.8. Bar chart Graph for OAC Determination

From Figure 8, the range of asphalt content that meets the specifications for the AC-WC mixture is 5.40% - 6.15%. So the OAC value is:

OAC = (A+B)/2 = (5.40 %+6.15 %)/2 = 5.78 %.

5.8 Asphalt Mixture Stability With Variations in PET Levels

The OAC value of 5.78% was then used as the asphalt content of the PET powder addition mixture with 5 variations namely; 0.25%, 0.50%, 0.75%, 1.00% and 1.25% by weight of the total asphalt for each type of mixture. The following presents the results of the stability analysis of the mixed test results.

Table.12. Stability Value of PET Asphalt Content Variation

PET Content (%)	Specification	Unit	Mixture Stability With PET Addition Variations				
			Asphalt Content(%)				
			5,00	5,50	6,00	6,50	7,00
0,25	> 1000	Kg	1354,53	1498,98	1600,40	1500,01	1493,11
0,50			1139,95	1145,68	1535,58	1523,48	1495,49
0,75			1469,22	1522,17	1654,79	1612,70	1558,07
1,00			1247,52	1358,58	1615,49	1586,99	1508,76
1,25			1501,50	2141,18	1895,73	1908,86	1831,47

From the data presented in Table 12, in order to make it easier to analyze changes in the stability of the mixture after the addition of PET powder, the data is displayed in graphical form below:

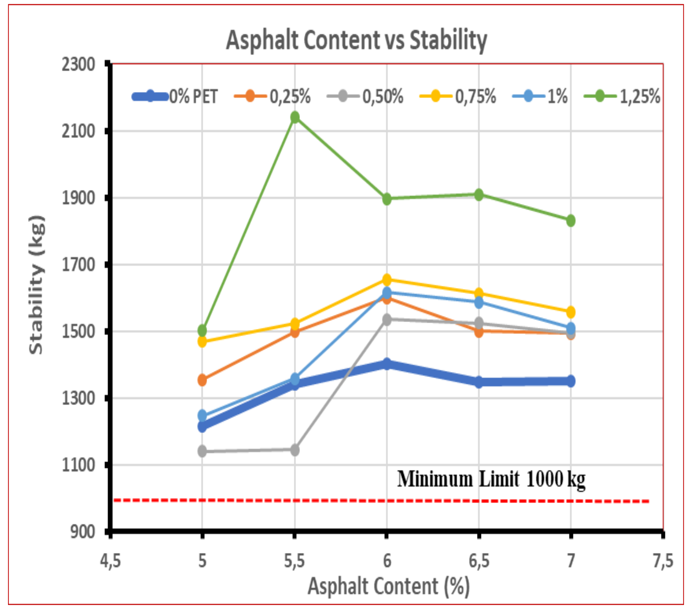

Fig.9. Relationship Between PET Variation and Mixture Stability

Based on Figure 9 above, several important things that can be summarized regarding the stability of the test specimens at various percentages of PET at each asphalt content used in the mixture are as follows:

1. The stability of the mixture in each variation of PET addition meets the required specifications, namely a minimum of 1000 kg.
2. Except for the 0.5% PET content, the addition of 0.25%, 0.75%, 1% and 1.25% PET crackle powder to asphalt causes an increase in stability.
3. Changes in stability with the addition of 0.25%, 0.75% and 1% PET showed the same pattern, where at 5% to 6% asphalt content there was an increase and then decreased from 6% to 7% asphalt content.
4. The pattern of change in stability that is different from point b above is seen in the addition of 1.25% PET, where from 5% to 6% asphalt content there is a significant increase in stability and then decreases slowly until the mixed asphalt content is 7%. Meanwhile, at 0.50% PET content, the stability change pattern is the same as point b above, only at asphalt content between 5% and 5.7% the stability is lower than the mixture without additives.
5. From the graph it can be seen that the increase or decrease in stability is not directly proportional to the content of PET powder added to the asphalt mixture.
6. The highest average stability of 1855.7 kg at all variations in asphalt content was recorded when the addition of 1.25% PET by weight of asphalt. This means that the addition of 1.25% PET has resulted in an increase in the ability of the asphalt mixture to carry loads which is characterized by an increase in the stability of the mixture on average by 39% from the initial conditions without PET. Meanwhile, the smallest increase in stability of 3% occurred with the addition of 0.5% PET to asphalt.

The following table summarizes the average percentage increase in the stability of the mixture after the addition of PET to asphalt.

Table.13. Stability Changes in PET Level Variations

PET Content (%)	Average Stability at 5 Asphalt Content (kg)	The Average Increase in Stability Due to the Addition of PET
Initial Condition (0%)	1331,8	0%
0,25	1489,4	12%
0,50	1368,0	3%
0,75	1563,4	17%
1,00	1463,5	10%
1,25	1855,7	39%

VI. CONCLUSION

Based on the results of the analysis of laboratory test data, the following conclusions can be drawn:

1. The stability of the mixture without and with the addition of PET powder meets the minimum specification requirement of 1000 kg.
2. To obtain the highest stability of the AC-WC asphalt mixture, which is around 39% from the initial conditions, it is better to add 1.25% PET to the asphalt.
3. A more realistic increase in the stability of the mixture with the addition of 0.25%, 0.75% and 1% LDPE resulted in a higher stability than the initial conditions, namely 12%, 17% and 10% respectively.

VII. RECOMMENDATION

1. Asphalt mixture test specimens (brickets) for several conditions need to be made more than 3, so if there is upnormal data (far from expectations) obtained from the test of the 3 intended test objects, then the bricket test is carried out again.
2. Further research is needed to find out what causes the stability value of asphalt mixtures to increase with the addition of certain levels of PET, while on the other hand some characteristics of the binder (asphalt) are not in line with the flexible properties of asphalt mixtures, for example a significant decrease in penetration and ductility values.
3. It is necessary to consider conducting a similar study using a binder (asphalt) with a greater penetration value, such as 80/100.

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