

Study of the Effect of Asphalt Heating on the Cavities of AC-WC Mixtures with Added Ldpe Plastic Using Sem and Xrf Analysis

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Abstract: In road construction, the compaction temperature of the asphalt mixture has a significant influence on the characteristics of the planned asphalt layer. The compaction process of hot asphalt mixture can cause a decrease in temperature, which is an important factor in road quality. The purpose of this study was to determine the effect of asphalt heating temperature on the voids of the AC-WC mixture with the addition of LDPE plastic using SEM and XRF analysis. This study was conducted at the Road Transportation Laboratory, Faculty of Engineering, Tadulako University and the Integrated Laboratory of Tadulako University. The results showed that the heating temperature greatly determines the quality of the AC-WC mixture with the addition of LDPE plastic. At an optimal temperature of around 160–170 °C, LDPE can melt well. Conversely, at temperatures that are too low (<150 °C) LDPE does not melt completely so that the mixture becomes inhomogeneous and the voids enlarge. Meanwhile, at temperatures that are too high (>200 °C) homogeneous mixing occurs which reduces voids and increases the resistance of the mixture. The addition of LDPE plastic increases the load-bearing capacity of the AC-WC asphalt mixture because LDPE is able to increase elasticity, bond strength between aggregate and asphalt, and the density of the mixture structure. The addition of LDPE plastic increases the load-bearing capacity, indicated by a density value of 2.57 grams/cm³. Changes in the characteristics of the mixture's cavities, which appear denser, smaller, and more uniform based on SEM analysis, are in line with the VIM value of 4.77%, VMA of 16.29%, and VFB of 77.75%. These conditions directly contribute to the increase in load-bearing capacity, as reflected in the Marshall stability value of 2236.09 kg.

Keywords: Asphalt Mixture Temperature, LDPE (Low-Density Polyethylene) Plastic, SEM (Scanning Electron Microscope), XRF (X-Ray Fluorescence).

I. INTRODUCTION

Roads, as strategic infrastructure, play a vital role in supporting the distribution of goods and services, population mobility, and increasing investment and access to public services. Therefore, they require strong, durable pavements that meet durability standards. In flexible pavement, asphalt is the main material, but its quality is greatly influenced by the compaction temperature which determines the characteristics and performance of the road layer; temperature mismatches during mixing, transporting, and compaction often cause quality degradation and premature damage. To increase stability while reducing the use of pure asphalt, Low Density Polyethylene (LDPE) plastic waste is used as a substitute for fine aggregate because it has been proven to increase the stability value of the mixture to a certain limit.

The purpose of this study was to determine the effect of asphalt heating temperature on the voids of the AC-WC mixture with the addition of LDPE plastic and to determine whether the addition of LDPE plastic is able to increase the load-bearing capacity indicated by changes in the voids of the mixture in the AC-WC asphalt tested using SEM and XRF analysis.

II. EXPERIMENTAL PROCEDURE

Several concepts and literature reviews that are related to and support the research object are as follows:

2.1 Asphalt Concrete Layer

Asphalt concrete is an element in road construction made from a combination of thick asphalt and aggregate materials, which are mixed and spread in hot conditions and compacted at a specific temperature. This pavement layer consists of a mixture of hard asphalt (AC-WC) and aggregate with a continuous gradation. The manufacturing process is carried out by mixing, spreading, and compacting it at a certain temperature. This layer functions as a structural surface layer as well as a foundation layer. The surface of this layer is made of a mixture of hard asphalt and aggregate with a continuous gradation, which has an important role in supporting traffic loads, protecting the construction underneath, acting as a wearing layer, and providing a flat and non-slip

surface. Several things that need to be considered in planning are the type of aggregate, aggregate gradation, aggregate quality, type of hard asphalt, planned pavement thickness, and the type of filler to be used.

2.2 AC-WC Mix Gradation

Gradation, or particle distribution based on aggregate size, plays a crucial role in determining the characteristics of pavement. Aggregate gradation influences the number of voids or pores that may form in the mixture. If the mixture consists solely of aggregates of the same size, numerous voids or pores will form because there are no smaller aggregates to fill the empty spaces. Conversely, if the aggregate mixture is evenly distributed from large to small, fewer voids or pores will form. This is because the gaps created by the arrangement of large aggregates are filled by smaller aggregates. Well-graded aggregates are aggregates with evenly distributed grain sizes across a single size range. These aggregates are also known as densely graded aggregates. Mixtures made from well-graded aggregates have fewer voids, are easy to compact, and offer high stability.

2.3 Modification Temperature

Asphalt is thermoplastic, meaning it hardens when the temperature decreases and softens when the temperature increases, thus varying degrees of sensitivity to temperature changes for each type. Understanding this temperature sensitivity is crucial in the mixing and compaction process of asphalt mixtures to achieve optimal temperatures that ensure pavement performance. Changes in compaction temperature can alter asphalt properties and trigger damage such as deformation and cracking due to the formation of cavities that accelerate oxidation, reduce adhesion, and make the mixture brittle. Therefore, a proper compaction process plays a crucial role in improving the stability and durability of road pavements, with commonly used modified compaction temperatures being 110°C, 120°C, 130°C, 140°C, 150°C, and 160°C.

2.4 Asphalt

Asphalt is the primary material in the construction of flexible pavements for highways. Its primary function is to bind aggregates, thanks to its strong adhesion, good adhesive properties, water resistance, and ease of processing. Asphalt is a plastic material that, due to its flexibility, can be easily mixed with aggregates. Asphalt, also known as bitumen, is a brownish-black material with viscoelastic properties. This property allows asphalt to soften and liquefy when heated, and conversely, harden when cooled. This viscoelastic property allows asphalt to coat aggregates and maintain them in place throughout the production process and its useful life. In general, asphalt is composed of hydrocarbon chains called bitumen, which is why it is often referred to as a bituminous material.

2.5 Gradation

All pavement specifications require aggregate particles to be within a specific size range, and each particle size must meet a predetermined proportion. This variation in aggregate grain size is referred to as aggregate gradation. Gradation, or particle distribution based on aggregate size, plays a crucial role in determining pavement stability. This aggregate gradation impacts the dimensions of the spaces between particles, which ultimately impacts stability and ease of application. The process of obtaining aggregate gradation is carried out through sieve analysis using a set of sieves with the coarsest sieve placed on top and the finest at the bottom.

2.6 Volumetric Asphalt Concrete Mixture

The volumetric asphalt mixture referred to is the volume of the compacted mixture test specimen. The volumetric components of the asphalt mixture are: Volume of voids between mineral aggregates (VMA), Volume of solid mixture bulk, Volume of solid mixture without voids, Volume of voids filled with asphalt (VFA), Volume of voids in the mixture (VIM), Volume of asphalt absorbed by the aggregate.

2.7 Low Density Polyethylene (LDPE) Plastic

Low Density Polyethylene (LDPE) plastic as an additive in asphalt mixtures. Plastics are classified as thermoplastics and thermosets, and the addition of LDPE can affect the VMA value because the plastic layer covers the aggregate and closes some of the cavities between the grains, especially in dense gradations. LDPE is chosen because it is easy to melt and process, with waste that must go through the stages of sorting, shredding, washing, and in dry and clean conditions. The percentage of use ranges from 4–6% of the asphalt weight. LDPE is a type of polyethylene resulting from the polymerization of ethene (C₂H₄) through a free radical process at high temperature and pressure, has a specific gravity of 0.91–0.94 gr/cm³, a melting point of around 150°C, is strong, flexible, somewhat translucent, chemically resistant, and has good water vapor protection. This plastic is commonly used in bottles, toys, buckets, pipes, cable insulation, and plastic bags.

2.8 Plastic and Asphalt Mixture

There are two methods of mixing plastic into asphalt mixtures: the wet method and the dry method. The wet method involves mixing plastic into hot asphalt using a high-speed mixer until homogeneous, but requires significant investment and operational costs, resulting in asphalt with a higher price than conventional asphalt. Meanwhile, the dry method involves adding plastic to hot aggregate before mixing it with asphalt, making the process simpler and requiring no additional equipment. However, attention must still be paid to ensuring uniformity in plastic content. The percentage of plastic used should not exceed 17% because it can alter the characteristics of the mixture to prevent it from meeting standards. While low-content additions (0.2%–1% of aggregate weight) can increase the density and stiffness of the mixture, potentially improving the performance and resistance of asphalt concrete to cyclical loading.

2.9 Scanning Electron Microscope (SEM)

Scanning Electron Microscope (SEM) is an electron microscope used to observe the microstructure of asphalt, including porosity and crack formation, by providing information on topography (surface characteristics and textures such as hardness and reflectivity), morphology (shape and size of constituent particles and material defects), composition (quantitative data of elements and compounds and their properties such as melting point and reactivity), and crystallography (grain arrangement in the material that affects conductivity, electrical properties, and strength).

2.10 X-Ray Fluorescence (XRF)

X-Ray Fluorescence (XRF) is a qualitative and quantitative elemental analysis method that works based on the interaction of high-energy X-rays with atoms on the sample surface. When X-rays hit an atom and their energy exceeds the binding energy of electrons in the K, L, or M shells, electrons are released, creating vacancies that are then filled by electrons from the outer shells, accompanied by the release of characteristic X-rays. The resulting spectrum consists of a continuous spectrum and a characteristic spectrum that is unique to each element. Element identification is carried out through characteristic X-ray energy peaks (qualitative analysis), while determination of the content is carried out by comparing the signal intensity of the sample to the standard (quantitative analysis). This method can be used to analyze samples in the form of massive solids, pellets, or powders.

III. RESULTS AND DISCUSSIONS

3.1 Research Location

This research was conducted at the Road Transportation Laboratory, Faculty of Engineering, Tadulako University and the Integrated Laboratory of Tadulako University.

3.2 Types of Research

This research is an experiment conducted in a laboratory with the aim of analyzing the characteristics of asphalt mixtures modified using Low-Density Polyethylene (LDPE) plastic as an additive. In this study, asphalt was mixed with LDPE in various percentages to evaluate its effect on voids in asphalt concrete. It is expected that the results of this study can provide insight into the potential use of LDPE plastic as an additive in asphalt, which can increase the durability and service life of road pavements.

3.3 Materials Used

1. Aggregate

Aggregate sources were selected based on technical criteria in accordance with the Indonesian National Standard (SNI). Material was taken from several stockpiles with varying aggregate grain sizes, including 3/4 and 3/8 crushed stone, and rock ash. This selection was intended to represent the entire sample population. The material was collected using a shovel, and the resulting material was placed in separate sacks according to the diameter of each aggregate fraction. The collected aggregate was then taken to the laboratory for further examination.

2. Asphalt

In this study, the asphalt used as a binder in the mixture was obtained from asphalt available at the Transportation and Highway Laboratory, Faculty of Engineering, Tadulako University, and the Integrated Laboratory of Tadulako University. The type of asphalt used in this study was 60/70 penetration hard asphalt. This asphalt is commonly used in road pavements in tropical climates because it has a good balance between flexibility and stiffness. The selection of this type of asphalt was based on its ability to provide optimal stability to the asphalt mixture. The asphalt material collection process was carried out carefully to ensure that the original properties of the asphalt were maintained. Asphalt collection was carried out by transferring the asphalt

from the drum containing the sample into a prepared container. After the sample was obtained, the container was tightly closed and placed in a safe location to avoid contamination with other materials. For easy identification, each sample was clearly labeled.

3. LDPE plastic

In this study, we used collected LDPE plastic waste. The selected LDPE plastic was shredded and sieved with a No. 4 sieve. We tested variations in the LDPE plastic content applied, namely 0%, 0.25%, 0.5%, 0.75%, and 1% based on the weight of the asphalt. Before being mixed into the asphalt, there are several plastic processing steps that must be carried out as follows:

- a) Plastic is prepared.
- b) Clean the plastic from dirt or substances stuck to the plastic, make sure the plastic is clean.
- c) The plastic is put into a chopping machine.

3.4 Research Procedures

The research procedure includes literature study as a theoretical basis using references from books, journals, articles, and previous research reports; preparation of research materials in the form of coarse aggregate, fine aggregate, filler, 60/70 penetration asphalt, and additional plastic materials of the LDPE (Low Density Polyethylene) type which are then tested; and material testing to determine their characteristics and suitability to the required specifications, including inspection of aggregates (coarse, fine, and filler) through sieve analysis, specific gravity testing, and absorption referring to the General Specifications of Bina Marga (2018). Asphalt testing is carried out using several methods, namely penetration testing, softening point, ductility, specific gravity, and weight loss.

The derivative with the lowest percentage of mortality was the ester formed by the condensation of ibuprofen with carvacrol (**5**), even though it presented 73% of mortality, that is, it was also very active. The same was followed by n-propyl ibuprofenate (**3**), which presented a mortality of 75%. The esters (**1** and **2**) formed by ibuprofen and the alcohols methanol and ethanol presented 97 and 82% mortality in relation to the insect. These mortality rates are higher than those reported in the literature, which describe the use of various commercial substances in pest control, reporting a maximum mortality rate of 85.5% with rotenone use among several other commercial products evaluated against the insect, *C. maculatus* (Azevedo et al., 2007). Ibuprofen derivatives also show higher toxicity to *C. maculatus* than the use of vegetable oils (Law-Ogbomo and Egharevba, 2006; Loni and Panahi, 2015; Tofel et al., 2017), secondary metabolites (Nenaah, 2013) and microorganisms (*Beauveria bassiana* e *Metarhizium anisopliae*) in control *C. maculatus*, reaching mortality of 80% (Mahdeshin et al., 2011). However, it is important to note that, from the experimental point of view, the synthesis, commercialization and storage of ibuprofen and derivatives has the advantage of being a simpler process than the isolation and cultivation of microorganisms.

Table 1. Aggregate Inspection Standards

No.	Types of Testing	Test Standards
1.	Specific gravity (bulk specific gravity, SSD specific gravity and apparent specific gravity) and fine aggregate absorption	SNI 03-1970-1990
2.	Specific gravity (bulk specific gravity, SSD specific gravity and apparent specific gravity) and coarse aggregate absorption	SNI 03-1969-1990
3.	Los Angeles Test	SNI 03-2417-2008
4.	Aggregate Impact Value Test (AIV)	BS 812: Part 3: 1975
5.	Aggregate Crushing Value Test (ACV)	BS 812: Part 3: 1975

The aggregates used in this study consist of coarse aggregates and fine aggregates which were first tested to ensure their conformity to specifications, including sieve analysis tests based on combined aggregate gradation for asphalt mixtures, specific gravity tests of coarse aggregates according to SNI 1969-2008 and fine aggregates according to SNI 1970-2008, as well as aggregate wear tests referring to SNI 2417-2008; in addition, in the matrix of test objects for determining the optimum asphalt content (PKAO), samples were taken from asphalt mixtures that had been added with LDPE plastic at a certain mixing temperature with variations in the planned conventional asphalt content.

Table 2. The Matrix of the Number of Test Objects Determines the KAO

No	No additives	PKAO					Amount
		4.0 %	4.5 %	5.0 %	5.5 %	6.0 %	
1	Conventional Asphalt	3	3	3	3	3	15
Total							15

Table 3. Matrix of the Number of KAO + LDPE Test Objects

No	LDPE content (%)	KAO + LDPE	Amount
1	0.00	3	6
2	0.25	3	6
3	0.50	3	6
4	0.75	3	6
5	1.00	3	6
Total			30

Table 4. Asphalt Testing Standards

No.	Types of Testing	Test Standards
1.	Penetration 25°C (mm)	SNI 06-2456-1991
2.	Softening point (°C)	SNI 06-2434-1991
3.	Specific gravity	SNI 06-2441-1991
4.	Losing weight	SNI 06-2440-1991
5.	Ductility at 25°C (cm)	SNI 06-2432-1991

3.5 Testing of Asphalt Concrete + LDPE at Optimum Asphalt Content (OAC) conditions

Before mixing, the gradation is determined based on the sieve size to determine the proportion of aggregate, not based on the percentage of each fraction in the combined gradation. The test begins by weighing the asphalt mixture test specimen of ± 1200 grams, then the coarse aggregate, fine aggregate, sand, rock dust, and filler are heated and stirred in a mixing pan until they reach the specified temperature, while the asphalt is heated separately with temperature variations and the addition of LDPE plastic. After reaching the mixing temperature, the aggregate is weighed and mixed into the asphalt that has been added with LDPE, then stirred quickly until the asphalt coats the entire surface of the aggregate, with the mixing temperature controlled using a thermometer throughout the process.

3.6 Testing of Asphalt Concrete + LDPE at Mixing Temperature

The test was conducted at the asphalt mixing temperature according to the standard specifications with an asphalt content of 5.0%, where each content was tested using three test specimens at different temperatures. Mix design is an important stage in the manufacture of PKAO, with the selection of materials adjusted to the AC-WC specifications and the determination of the composition of coarse aggregate, fine aggregate, and filler to achieve ideal gradation and good intergranular bonding. The AC-WC mix design in this study uses the Marshall method to determine the optimum asphalt content so that the aggregate and asphalt composition that meets the technical requirements of road pavement is obtained.

3.7 Marshall Characteristic Testing

Marshall characteristic values are obtained through analysis of data collected from laboratory experiments. Marshall characteristic testing is carried out using the following steps:

1. Stability
2. VMA (Void in Mineral Aggregate)
3. VIM (Void in The Mix)
4. VFB (Void Filled with Bitumen)
5. Melting (Flow)
6. Density
7. Marshall Quotient

3.8 Volumetric Data Analysis of AC-WC Mixture

Data analysis was conducted to evaluate the Marshall characteristic parameters of asphalt mixtures, both those containing and without LDPE plastic. This study involved LDPE plastic levels of 0%, 0.25%, 0.5%, 0.75%, and 1%. The results of the data processing will be presented in graphical form showing the relationship between asphalt content and Marshall parameters.

3.9 Processing and Discussion of Results

Data analysis for the results of Scanning Electron Microscope (SEM) and X-Ray Fluorescence (XRF) tests in this study was conducted to evaluate the microstructure and chemical composition of asphalt mixtures modified with Low-Density Polyethylene (LDPE). Data from the SEM test were analyzed by observing the surface morphology, the distribution of LDPE in the asphalt matrix, and the presence of cracks or gaps between materials. Meanwhile, the results of the XRF test were used to determine the elements and chemical compounds in the mixture, especially to determine changes in elemental composition due to the addition of LDPE. The results of these two analyses were then compared with conventional asphalt to assess the improvement or changes in characteristics that occurred after modification with LDPE. Data interpretation was carried out qualitatively and quantitatively to understand the extent to which LDPE can improve the performance of asphalt in road pavements.

IV. CONCLUSION

4.1 Determination of Aggregate Composition of AC-WC Mixture

The determination of the aggregate composition of the AC-WC mixture uses the by Portion method, which groups aggregates based on fractions of coarse and fine aggregates. The composition determination can be seen in the table below.

Table 5. Results of Determination of AC Mixed Aggregate Composition WC

Sieve Size	Size (mm)	Fraksi 3/4"		Fraksi 3/8"		Rock ash		Combined Gradation	2018 Highways Specifications	
		% Passing	13 %	% Passing	37 %	% Passing	50 %			
3/4 *	19.00	100.00	13.000	100.00	37.000	100.00	50.000	100	100.00	
1/2 *	12.50	25.19	3.274	100.00	37.000	100.00	50.000	90	90	- 100
3/8 *	9.50	2.98	0.388	98.87	36.584	100.00	50.000	87	77	- 90
#4	4.75	0.55	0.071	41.83	15.478	95.47	47.736	63	53	- 69
#8	2.36	0.51	0.066	9.75	3.607	69.82	34.909	39	33	- 53
#16	1.18	0.49	0.064	3.74	1.385	47.14	23.570	25	21	- 40
#30	0.60	0.46	0.060	2.80	1.035	31.81	15.905	17	14	- 30
#50	0.30	0.45	0.058	2.37	0.878	23.33	11.666	13	9	- 22
#100	0.15	0.41	0.054	1.82	0.674	14.87	7.437	8	6	- 15
#200	0.08	0.36	0.047	1.21	0.449	8.20	4.102	5	4	- 9
PAN	-	0.00	0.000	0.00	0.000	0.00	0.000	0	-	

From the table above, the results of the mixture gradation test show that the percentage of material passing the 3/4" sieve reaches 100%, the 1/2" sieve is 90%, the 3/8" sieve obtains 87%, the No. 4 sieve reaches 63%, the No. 8 sieve is 39%, the No. 16 sieve reaches 25%, the No. 30 sieve obtains 17%, the No. 50 sieve is 13%, the No. 100 sieve reaches 8%, and the No. 200 sieve is 5%. Based on the analyzed percentages, these test results meet the 2018 Bina Marga standards for the manufacture of AC-WC laston mixtures. Furthermore, the results of the mixture gradation can be seen in the graph below:

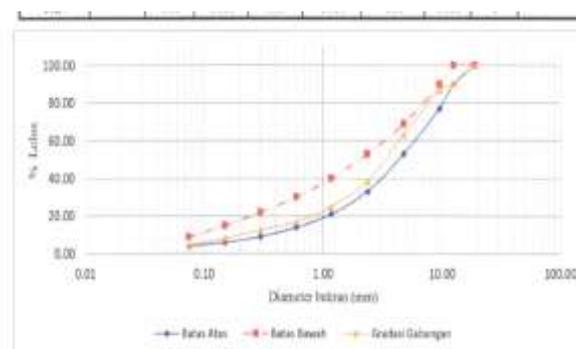


Figure 1. Combined Gradation Graph of Laston AC-WC Mixture

Determination of Estimated Optimum Asphalt Content (PKAO):

- FF = 4.60%
- CA = 100% - (% Pass No.8)
= 100% - 39%
= 61%
- FA = (% Pass No.8) - % Filler
= 39% - 4.60%
= 34.40%
- C = Constant is taken as 0.5 (Constant Value 0.5-1.0 for Laston)
- Pb = 0.035 (% CA) + 0.045 (%FA) + 0.18 (%FF) + C
= 0.035 (61%) + 0.045 (34.40%) + 0.18 (4.60) + 0.5
= 5.01%

After the initial estimated value (Pb) is obtained, the asphalt content variation is determined by taking two values above and one below the content. In this study, asphalt content ranging from 4% to 6% was used with an asphalt content interval of 0.5%.

4.2 Determination of Optimum Asphalt Content (OAC) Using Marshall Testing

The test specimens, prepared according to the aggregate composition and estimated best asphalt content, were left to cure for 24 hours. They were then immersed in a water bath at 60°C for 30 minutes and then tested using a Marshall pressure tester. The results of the Marshall test can be found in the following table and graph.

Table 6. Marshall Test Results for Determining Asphalt Content Optimum (KAO)

Test Type	Unit	Test Results per Asphalt Content (%)					Spek.
		4	4.5	5	5.5	6	
Density	(gr/cm3)	2.31	2.36	2.39	2.40	2.44	
VIM	(%)	8.72	5.96	4.06	3.08	0.91	3 - 5 %
VMA	(%)	17.52	16.09	15.46	15.65	14.83	Min 15
VFB	(%)	50.24	62.99	74.11	80.45	93.87	Min 65
Stability	(Kg)	707.68	959.89	1008.84	944.26	904.83	Min 800 kg
Flow	(mm)	3.63	3.76	3.49	4.80	5.24	2 - 4
MQ	(Kg/mm)	194.10	260.95	265.90	195.07	166.90	Min 250

Based on the table above, a graph of the relationship between asphalt content and each Marshall test parameter is then made, the relationship graph can be seen as follows.

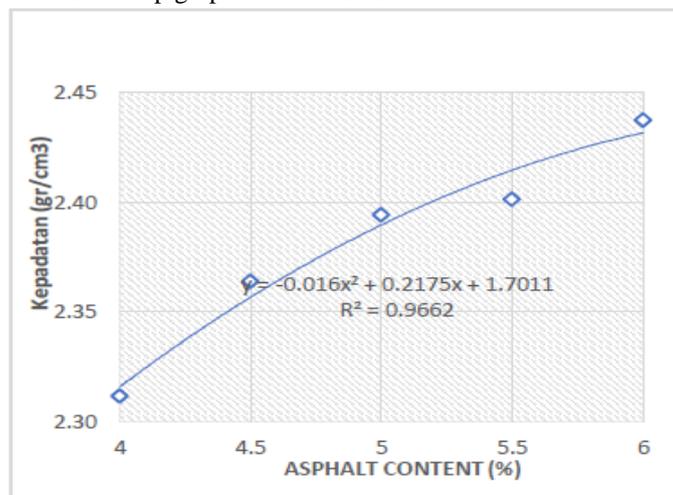


Figure 2. Graph of the Relationship between Asphalt Content and Density

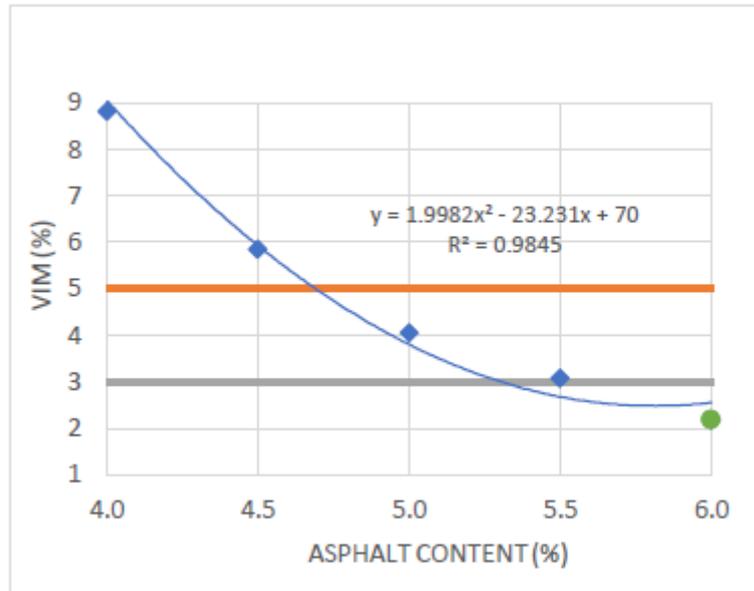


Figure 3. Graph of the Relationship between Asphalt Content and VIM

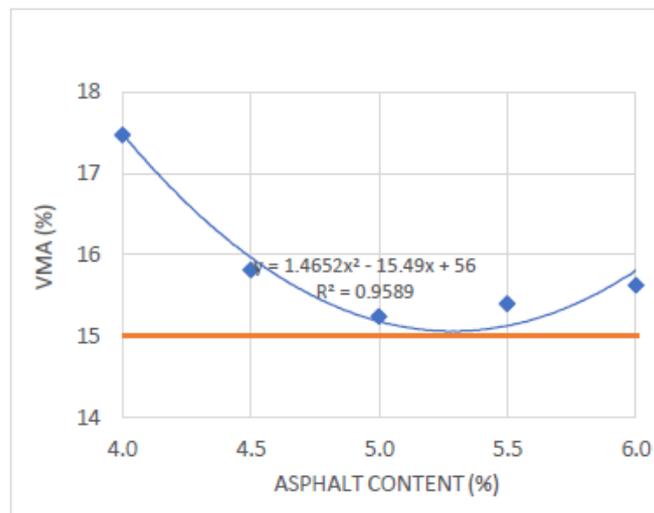


Figure 4. Graph of the Relationship between Asphalt Content and VMA

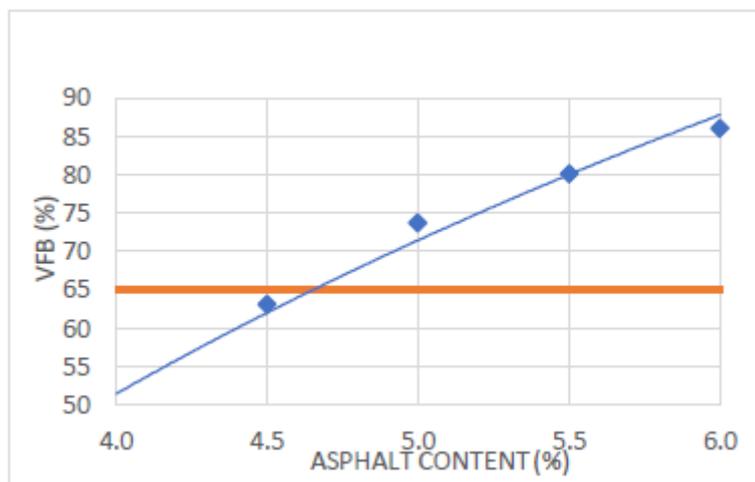


Figure 5. Graph of the Relationship between Asphalt Content and VFB

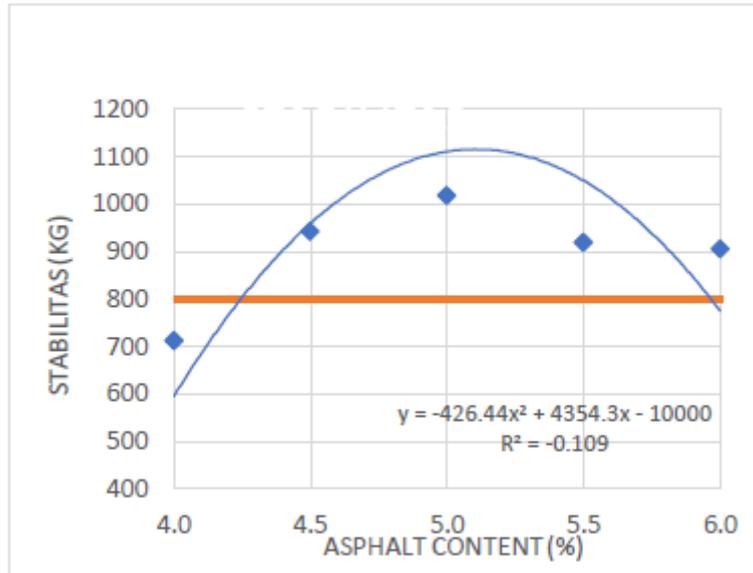


Figure 6. Graph of the Relationship between Asphalt Content and Stability

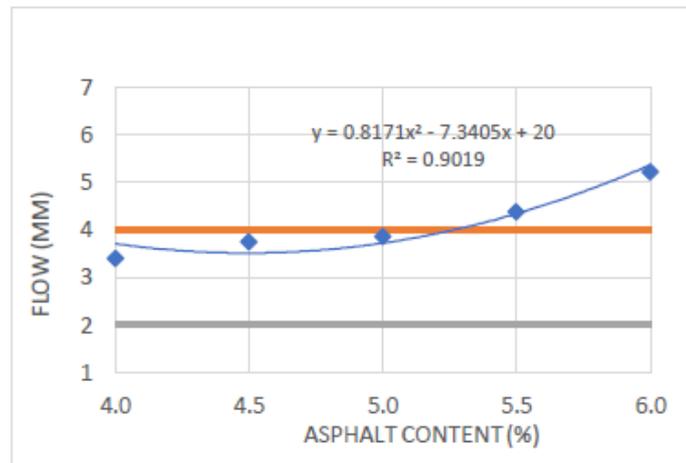


Figure 7. Graph of the Relationship between Asphalt Content and Flow

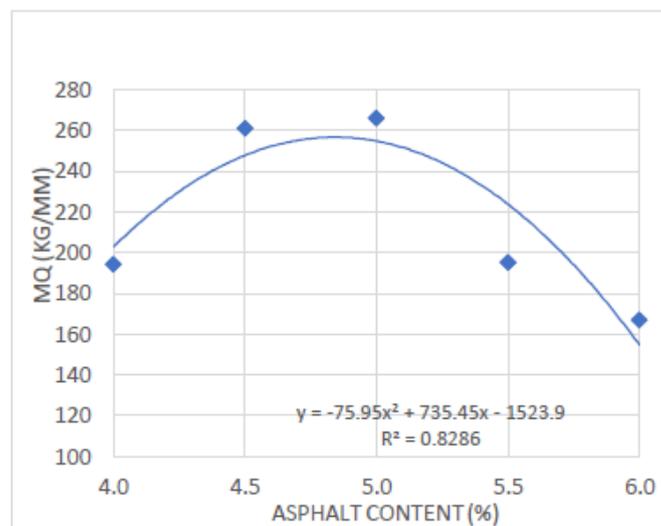


Figure 8. Graph of the Relationship between Asphalt Content and MQ

Based on the graphs of each Marshall test parameter shown above, the applicable specifications can be seen. Next, a graph was created to determine the asphalt content range that meets the specifications and to determine the Optimum Asphalt Content (OAC), as shown in the graph below.

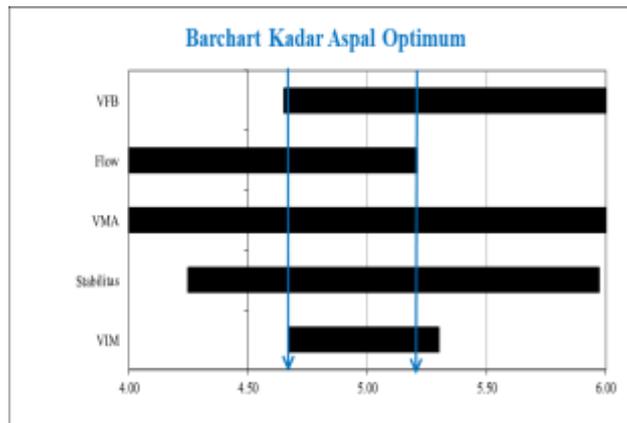


Figure 9. Barchart for Determining Optimum Asphalt Content (OAC)

The figure above shows the range of AC-WC asphalt content between 4.67% and 5.21%. Therefore, the KAO (Optimum Asphalt Content) value is as follows.

KAO

Based on the results obtained, namely 5% asphalt content, the KAO value was then used for asphalt testing with LDPE.

4.3 Marshall Testing of AC-WC + LDPE Mixture

Marshall testing on asphalt mixtures with LDPE was conducted using an ideal asphalt content of 5% and varying LDPE content of 0.25%, 0.5%, 0.75%, and 1%. Each LDPE content requires a different mixing temperature. This temperature is determined through viscosity testing. The following are the mixing temperatures used according to each LDPE content.

Table 7. Mixing Temperature Based on LDPE Content

No.	LDPE content (%)	Mixing Temperature (°C)
1	0.00	167 – 173
2	0.25	207 – 210
3	0.50	207 – 213
4	0.75	214 – 220
5	1.00	228 – 230

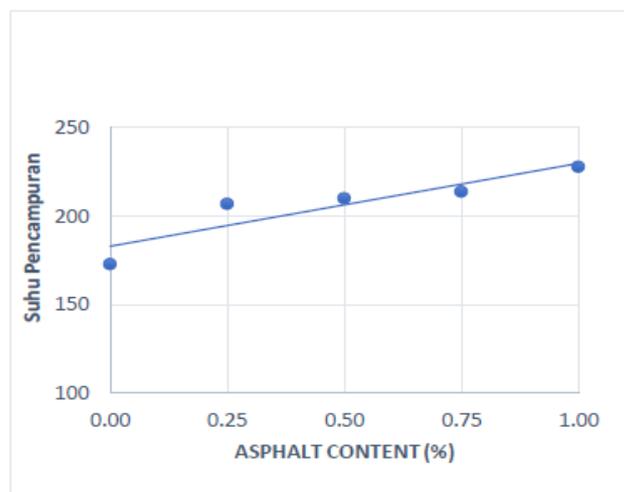


Figure 10. Relationship between LDPE Content and Mixing Temperature

Based on the figure above, the increasing use of LDPE plastic also requires a higher mixing temperature. This indicates that viscosity increases, requiring more heat to melt the LDPE. Therefore, a higher mixing temperature is required to ensure a homogeneous, manageable asphalt and LDPE mixture capable of producing mixture voids (VIM, VMA, VFB) that meet standards.

4.4 Marshall Asphalt + LDPE Test Parameter Analysis Results

The Marshall parameter calculations for asphalt and plastic mixtures are the same as those for conventional asphalt mixtures. The following are the test results.

Table 8. Marshall Asphalt + LDPE Test Results

No	Marshall Parameters	Unit	Test Results per Asphalt Content (%)					Spek
			0%	0.25	0.5	0.75	1	
1	Density	(gr/cm3)	2.46	2.47	2.46	2.45	2.46	
2	VIM	(%)	4.35	4.07	4.42	4.77	4.34	3 - 5%
3	VMA	(%)	16.13	15.89	16.20	16.50	16.13	Min 1
4	VFB	(%)	73.08	74.40	72.78	71.12	73.09	Min 6
5	Stability	(Kg)	1051.67	1724.00	1865.06	2010.54	2357.24	Min 8
6	Flow	(mm)	3.58	3.53	3.62	3.26	3.15	2 - 4
7	MQ	(Kg/mm)	288.49	465.01	497.24	584.16	708.41	Min 2

4.5 Analysis Using SEM (Scanning Electron Microscope) With the Addition of 0% LDPE Plastic

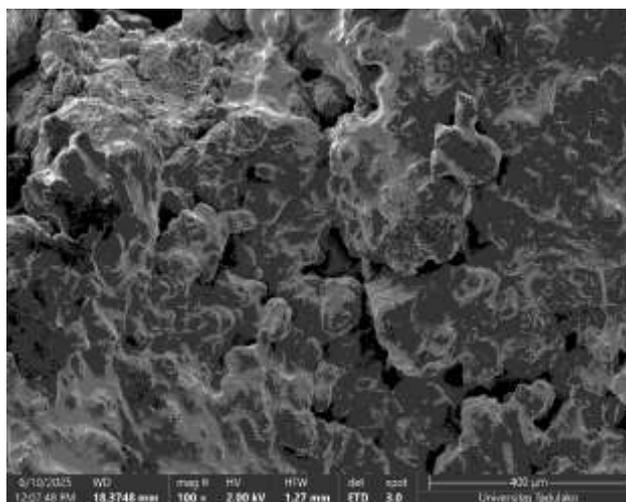


Figure 11. Scanning Electron Microscope (SEM) Test Results with 0% LDPE Plastic Addition

The results of SEM testing at 80x magnification showed that the surface of the asphalt mixture with aggregates had many irregular cavities, micro voids that were rounded or not completely filled, and coarse and inhomogeneous porous areas. This condition indicates that the asphalt heating temperature was possibly not optimal, so that the asphalt viscosity was high and difficult to flow into the gaps between the aggregates, causing inhomogeneous mixing, the formation of asphalt lumps that did not unite, and the surface of the AC-WC mixture without LDPE (0%) was not dense, the aggregates were not perfectly bound, and voids were formed extensively.

4.6 Analysis Using SEM (Scanning Electron Microscope) With the Addition of 0.25% LDPE Plastic

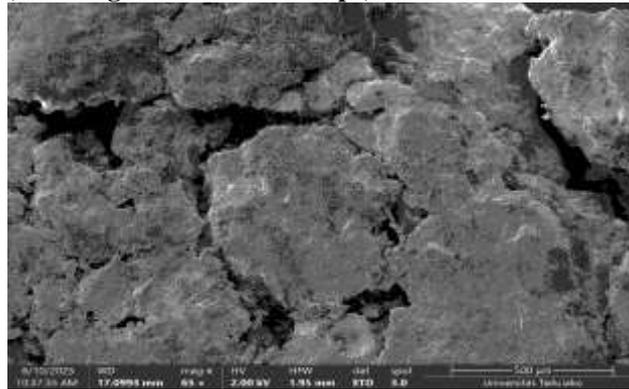


Figure 12. Scanning Electron Microscope (SEM) Test Results with 0.25% LDPE Plastic Addition

LDPE plastic, which has a lower melting temperature than asphalt, can melt and mix well at the ideal asphalt heating temperature, forming a more optimal asphalt-polymer matrix. Heating too low will prevent LDPE from melting completely, while too high a temperature can cause plastic degradation and the formation of voids or pores in the mixture, as seen in SEM testing. These voids indicate an imperfect interaction between asphalt, aggregate, and LDPE, or uneven heat distribution. The addition of 0.25% LDPE can help reduce the void size, improve strength distribution, and improve the thermal stability of the mixture, but its effectiveness depends on proper heating to maintain the quality of the bond between the aggregate and asphalt.

4.7 Analysis Using SEM (Scanning Electron Microscope) With the Addition of 0.50% LDPE Plastic

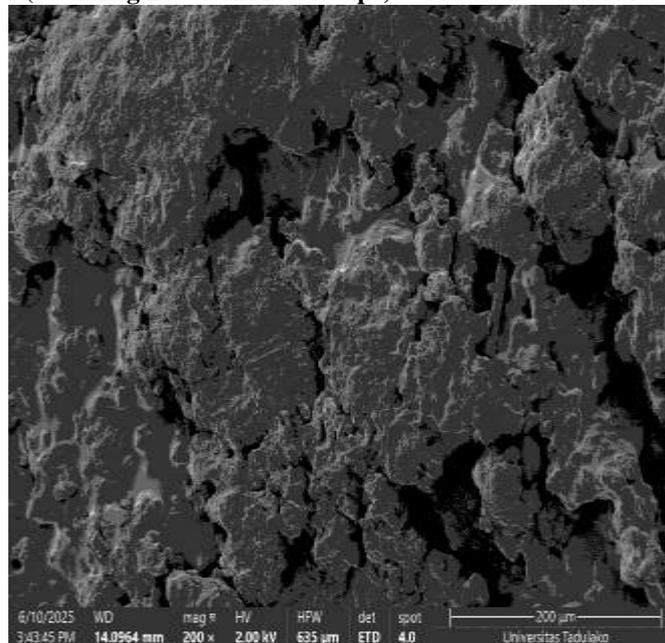


Figure 13. Scanning Electron Microscope (SEM) Test Results with 0.50% LDPE Plastic Addition

From the SEM test results, it can be seen that the surface is not homogeneous, with many voids and aggregates that are not perfectly bound. The cavities look quite large and are unevenly distributed, which indicates imperfections in compaction or mixing. Based on the test results, it can be concluded that the visible cavities indicate imperfections in mixing or heating, in the addition of 0.50% LDPE, the heating temperature must be controlled optimally so that the plastic melts completely and fills the space between the aggregates, and the temperature used is less than optimal or the heat distribution is uneven, causing LDPE to not function effectively as a filler/binder.

4.8 Analysis Using SEM (Scanning Electron Microscope) With the Addition of 0.75% LDPE Plastic

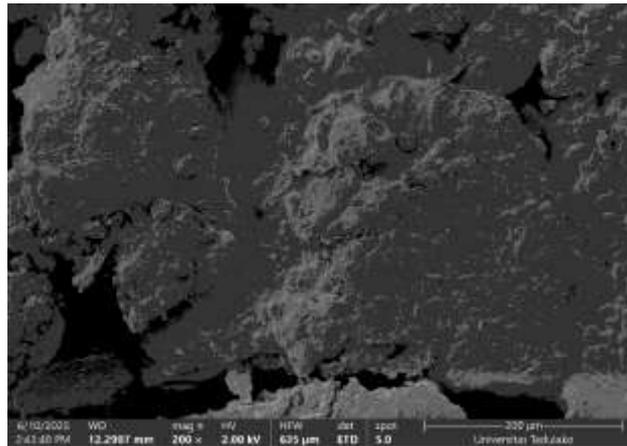


Figure 15. Scanning Electron Microscope (SEM) Test Results with 0.75% LDPE Plastic Addition

From the SEM test results, it can be seen that there are voids with quite large and uneven sizes. The aggregate and asphalt matrix are not perfectly combined. The surface shows the presence of micro cracks and open pores. Based on the test results, it can be concluded that the large voids and uneven distribution indicate that the heating process may not be optimal and the temperature is too low or uneven so that the LDPE is not distributed homogeneously and is unable to fill the voids between the aggregates properly. As a result, the mixture is less dense and can impact pavement performance such as water and traffic resistance. Some parts show that the aggregate is not completely coated by asphalt, possibly indicating problems in the distribution of LDPE or heating.

4.9 Analysis Using SEM (Scanning Electron Microscope) With the Addition of 1% LDPE Plastic

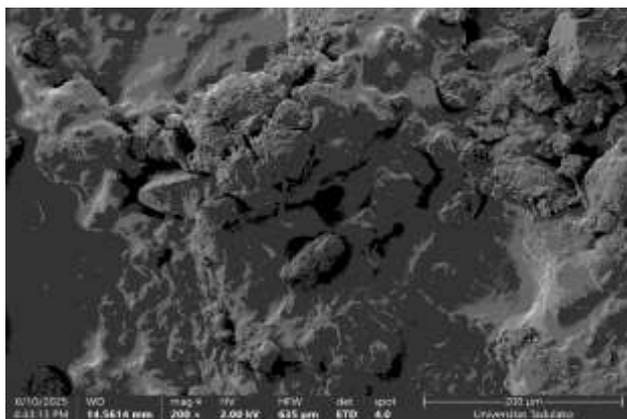


Figure 16. Scanning Electron Microscope (SEM) Test Results with 1% LDPE Plastic Addition

SEM test results show that the surface of the AC-WC mixture with 1% LDPE appears rough with several grains and cavities, which are affected by the asphalt heating temperature. Proper heating makes the asphalt more fluid so that the LDPE is evenly distributed, strengthening the structure, increasing mechanical resistance, and reducing cracks. Conversely, too high a temperature can cause LDPE degradation, the formation of larger cavities, and material segregation, reducing the quality of the mixture. Thus, optimal heating is very important to maintain structural stability, even material distribution, and good mixture quality.

4.10 The addition of LDPE plastic can increase the load-bearing capacity by changing the voids in the AC-WC asphalt mixture.

LDPE (Low Density Polyethylene) plastic added to AC-WC asphalt increases the viscosity and elasticity of the binder, making the mixture stiffer yet elastic, able to withstand repeated loads, and reducing permanent deformation. LDPE fills the micro voids, binds the aggregate more strongly, and produces a denser and more uniform mixture structure. SEM analysis shows an even distribution of LDPE on the aggregate surface, smaller and more homogeneous voids, a more compact surface, and reduced micro cracks, confirming that LDPE improves the stability, density, and load-bearing ability of the asphalt mixture.

4.11 Analysis Using XRF (X-Ray Fluorescence) With the Addition of 0% LDPE Plastic

Based on the XRF results of the AC-WC mixture without LDPE (0%) weighing 6.8643 grams and a Light Element (LE) value of 54.149%, it can be concluded that the mixture has a high content of light elements and/or voids, which mostly come from asphalt and air. A high LE value indicates that the asphalt heating is not optimal: if it is too low, the asphalt does not coat the aggregate evenly so that the voids remain large; if it is too high, the asphalt undergoes thermal degradation and loses volatile compounds, creating additional voids. The absence of LDPE means there is no additional material to fill or stabilize the voids, so proper heating temperature control is crucial to minimize voids and reduce the LE value, ensuring even asphalt distribution and optimal mixture performance.

4.12 Analysis Using XRF (X-Ray Fluorescence) With the Addition of 0.25% LDPE Plastic

Based on the XRF results of the AC-WC mixture with 0.25% LDPE addition and a sample weight of 6.9898 grams, the Light Element (LE) value of 59.261% indicates a high content of volatile elements, indicating that some organic materials and plastics evaporate. This indicates that the heating temperature is likely too high, causing thermal degradation of LDPE, gas formation, and an increase in voids even though LDPE is added to fill the pores and increase the stability of the mixture. Thus, although the addition of LDPE has the potential to reduce voids at optimal temperatures, excessive heating actually increases volatility and internal voids, reducing the homogeneity of the mixture and the effectiveness of the plastic as an additive.

4.13 Analysis Using XRF (X-Ray Fluorescence) With the Addition of 0.50% LDPE Plastic

Based on the XRF results on the AC-WC mixture with the addition of 0.5% LDPE and a sample weight of 9.4167 grams, the Light Element (LE) value of 58.158% indicates a high content of volatile compounds due to evaporation from thermal degradation of LDPE when heating exceeds the safe threshold. This indicates the formation of air cavities (voids) in the mixture, which can reduce the homogeneity and mechanical performance of the asphalt layer. This conclusion emphasizes the importance of heating temperature control so that LDPE can optimally combine with asphalt, reduce voids, and increase the stability and durability of the mixture against deformation, traffic loads, and weather conditions.

4.14 Analysis Using XRF (X-Ray Fluorescence) With the Addition of 0.75% LDPE Plastic

Based on the XRF results on the AC-WC mixture with the addition of 0.75% LDPE and a sample weight of 8.9261 grams, the Light Element (LE) value of 56.881% indicates significant evaporation of volatile components due to LDPE degradation when heating is too high. This causes the formation of air voids in the mixture, reducing the density, homogeneity, and durability of the asphalt layer. These data emphasize that the heating temperature greatly affects the distribution of LDPE and the number of voids, so proper heating control is important to prevent plastic degradation, minimize voids, and maintain the mechanical performance of the AC-WC mixture.

4.15 Analysis Using XRF (X-Ray Fluorescence) With the Addition of 1% LDPE Plastic

1% LDPE serves to fill small cavities and improve the bond between particles, as long as the heating temperature is sufficient to melt the LDPE, but not too high that the LDPE decomposes. When 1% LDPE is added to the AC-WC mixture, the LDPE melts during heating and mixes with the asphalt. If the temperature is too high, the LDPE can degrade to form gas or by-products, also adding voids. The high Loss on Evaporation (55.875%) indicates a large evaporation, including from the LDPE component. Effects on Mixed Voids (Voids) Voids tend to increase because high evaporation produces gas bubbles in the mixture, unstable LDPE produces empty spaces when evaporated, and decreased mixing homogeneity. So based on XRF research on the AC-WC mixture without additional LDPE (1%) with a sample weight of 8.5357 grams and an L.E value of 55.875%, it can be concluded that heating temperatures that are too high or too low can have a direct impact on voids in the AC-WC mixture modified with 1% LDPE. XRF analysis, particularly the high LE value (55.875), indicates the evaporation of light compounds, which contributes to the increase of voids in the mixture. Therefore, temperature control is crucial in the mixing process of plastic-modified asphalt.

V. ACKNOWLEDGEMENT

Based on the research conducted, the heating temperature greatly affects the quality of the AC-WC mixture with the addition of LDPE plastic, where the optimal temperature of 160–170 °C allows the LDPE to melt completely so that a homogeneous distribution of asphalt and aggregate and minimum air voids are achieved, while too low a temperature (<150 °C) produces an inhomogeneous mixture and too high a temperature (>200 °C) increases the density of the mixture. The addition of LDPE increases the elasticity, bonding between aggregate and asphalt, and the density of the mixture, indicated by a density of 2.57 g/cm³ and the characteristics of denser, smaller, and uniform voids (VIM 4.77%, VMA 16.29%, VFB 77.75%), which

contributes to an increase in the load-bearing capacity with Marshall stability of 2236.09 kg. SEM and XRF analysis support these findings by showing an even distribution of LDPE and optimal void conditions of the mixture.

REFERENCES

- [1]. Masárová, "IMPORTANCE OF ROAD INFRASTRUCTURE IN THE ECONOMIC DEVELOPMENT AND COMPETITIVENESS," *ECONOMICS AND MANAGEMENT*, vol. 18, no. 2, Aug. 2013, doi: 10.5755/j01.em.18.2.4253.
- [2]. A. S. Lubis, Z. A. Muis, and N. A. Siregar, "The effects of low-density polyethylene (LDPE) addition to the characteristics of asphalt mixture," in *IOP Conference Series: Earth and Environmental Science*, Institute of Physics Publishing, Jun. 2020. doi: 10.1088/1755-1315/476/1/012063.
- [3]. H. M. Radzi, R. Muniandy, S. Hassim, T. H. Law, and F. M. Jakarni, "An overview of asphalt mix designs using various compactors," in *IOP Conference Series: Materials Science and Engineering*, Institute of Physics Publishing, Apr. 2019. doi: 10.1088/1757-899X/512/1/012031.
- [4]. L. Bruno, G. Parla, and C. Celauro, "Image analysis for detecting aggregate gradation in asphalt mixture from planar images," *Constr. Build. Mater.*, vol. 28, no. 1, pp. 21–30, Mar. 2012, doi: 10.1016/j.conbuildmat.2011.08.007.
- [5]. W. S. Abdullah, A. Member, M. Taleb, O. / Associate, and N. M. Abu-Sa'da, "INFLUENCE OF AGGREGATE TYPE AND GRADATION ON VOIDS OF ASPHALT CONCRETE PAVEMENTS."
- [6]. Y. Malewar, S. Saleem, and A. Titiksh, "Gap Grading of Aggregates & Its Effect on The Inherent Properties Of Concrete," 2017.
- [7]. M. ENIEB, A. ELTWATĪ, and M. A. AL-JUMAILĪ, "Temperature sensitivity and performance evaluation of asphalt cement incorporating different types of waste polymers," *Journal of Innovative Transportation*, vol. 2, no. 2, pp. 0–0, Dec. 2021, doi: 10.53635/jit.984159.
- [8]. Y. Chen, N. Hossiney, X. Yang, H. Wang, and Z. You, "Application of Epoxy-Asphalt Composite in Asphalt Paving Industry: A Review with Emphasis on Physicochemical Properties and Pavement Performances," 2021, Hindawi Limited. doi: 10.1155/2021/3454029.
- [9]. M. V Mohod and K. N. Kadam, "A Comparative Study on Rigid and Flexible Pavement: A Review," *IOSR Journal of Mechanical and Civil Engineering (IOSR-JMCE)*, vol. 13, no. 3, pp. 84–88, doi: 10.9790/1684-1303078488.
- [10]. J. M. Krishnan and K. R. Rajagopal, "Review of the uses and modeling of bitumen from ancient to modern times," Mar. 2003. doi: 10.1115/1.1529658.
- [11]. Y. Zhang, X. Luo, I. Onifade, X. Huang, R. L. Lytton, and B. Birgisson, "Mechanical evaluation of aggregate gradation to characterize load carrying capacity and rutting resistance of asphalt mixtures," *Constr. Build. Mater.*, vol. 205, pp. 499–510, Apr. 2019, doi: 10.1016/j.conbuildmat.2019.01.218.
- [12]. C. F. Mora, A. K. H. Kwan, and H. C. Chan, "PARTICLE SIZE DISTRIBUTION ANALYSIS OF COARSE AGGREGATE USING DIGITAL IMAGE PROCESSING," 1998.
- [13]. G. D. Airey and A. C. Collop, "Mechanical and structural assessment of laboratory- and field-compacted asphalt mixtures," *International Journal of Pavement Engineering*, vol. 17, no. 1, pp. 50–63, Jan. 2016, doi: 10.1080/10298436.2014.925551.
- [14]. A. S. Lubis, Z. A. Muis, and N. A. Siregar, "The effects of low-density polyethylene (LDPE) addition to the characteristics of asphalt mixture," in *IOP Conference Series: Earth and Environmental Science*, Institute of Physics Publishing, Jun. 2020. doi: 10.1088/1755-1315/476/1/012063.
- [15]. H. Chandara, "Plastic Recycling in Indonesia ... (Hin Chandara, et al.) PLASTIC RECYCLING IN INDONESIA BY CONVERTING PLASTIC WASTES (PET, HDPE, LDPE, and PP) INTO PLASTIC PELLETS." [Online]. Available: <http://journal.ugm.ac.id/index.php/ajse>
- [16]. H. R. Radeef et al., "Enhanced Dry Process Method for Modified Asphalt Containing Plastic Waste," *Front. Mater.*, vol. 8, Jul. 2021, doi: 10.3389/fmats.2021.700231.
- [17]. A. Mohammed and A. Abdullah, "SCANNING ELECTRON MICROSCOPY (SEM): A REVIEW."
- [18]. T. D. T. Oyedotun, "X-ray fluorescence (XRF) in the investigation of the composition of earth materials: a review and an overview," *Geology, Ecology, and Landscapes*, vol. 2, no. 2, pp. 148–154, Apr. 2018, doi: 10.1080/24749508.2018.1452459.