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The Effect of Using Liquid Latex as an Additive in Asphalt Concrete–Wearing Course (AC-WC) Mixtures on Marshall Characteristics

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Abstract: Population growth and increasing economic activities have raised the demand for durable and high-quality road infrastructure. However, the Asphalt Concrete–Wearing Course (AC-WC), which functions as the surface layer of flexible pavements, often suffers from premature damage such as cracking and deformation due to heavy traffic loads and extreme weather. Therefore, improvements in asphalt mixture materials are necessary. One alternative is the use of liquid latex derived from natural rubber as an additive. Owing to its high elasticity, liquid latex is expected to improve flexibility, crack resistance, and durability of asphalt mixtures. This study aims to evaluate the effect of liquid latex addition on the Marshall characteristics of AC-WC mixtures and to determine the optimum latex content. The research employed laboratory experimental methods using liquid latex contents of 0%, 2.5%, 5%, 7.5%, and 10%, with three specimens prepared for each variation. The evaluated parameters included stability, flow, air voids in the mix (VIM), voids in mineral aggregate (VMA), voids filled with asphalt (VFA), Marshall Quotient (MQ), and density. The results indicate that liquid latex significantly affects all Marshall parameters. However, excessive latex content reduces mixture performance. The optimum condition was achieved at 2.5% liquid latex with an asphalt content of 5.65%, producing a stability of 1102.2 kg, flow of 3.13 mm, VIM of 3.87%, VMA of 17.01%, VFA of 77.26%, MQ of 355.15 kg/mm, and density of 2.297 g/cc. All parameters satisfy the 2018 Bina Marga General Specifications (Revision 2).

Keywords: AC-WC; Additive; Liquid Latex; Marshall Characteristics; VFA.

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1. Introduction

Road pavement is an important element in the transportation system that plays a major role in supporting mobility, regional connectivity, and economic development. In Indonesia, one of the most commonly used types of pavement is asphalt concrete wearing course (AC-WC), which is the top layer of flexible pavement that functions as a wearing course and protects the pavement structure underneath [1]. As a layer that interacts directly with traffic loads and the environment, AC-WC is susceptible to structural and functional damage, such as cracking and permanent deformation, triggered by excessive vehicle loads, high rainfall, increased traffic volume, and extreme road surface temperatures [2]. Various approaches have been developed to improve the performance of asphalt mixtures, mainly through material modification. Commonly used methods include adding synthetic polymers, chemical additives, and natural elastomers to asphalt mixtures [3]. The use of synthetic polymers has been proven to improve stability and deformation resistance, but has limitations in terms of high production costs and dependence on imported materials [4]. In contrast, natural elastomers such as natural rubber and liquid latex offer advantages in terms of sustainability, local availability, and the potential to increase mixture flexibility, although further research is needed on the optimum content and its effect on the mechanical characteristics of the mixture [5].

Road damage in Indonesia remains a serious problem. Data from the Directorate General of Highways shows that in 2023, the length of roads with minor damage will reach 62,435 km, while those with severe damage will reach 127,387 km [6]. The high rate of damage indicates the need to improve the quality of pavement design and materials, especially for the

AC-WC layer as the surface layer. As the second largest producer of natural rubber in the world, Indonesia has a great opportunity to utilize rubber for the road construction sector [7]. Liquid latex, which is a natural rubber product, has good elasticity, plasticity, and adhesion properties, thus having the potential to improve the performance of asphalt mixtures, especially in terms of stability, flexibility, and resistance to cracking [8]. Several previous studies have reported that the addition of liquid latex can improve the Marshall characteristics of AC-WC mixtures. However, detailed information regarding the effect of liquid latex content on each Marshall parameter and the determination of the optimum content is still limited [9]. Based on these issues, this study proposes an experimental approach using liquid latex as an additive in AC-WC asphalt mixtures. This study aims to evaluate the effect of liquid latex addition on Marshall characteristics and determine the optimum content that meets the 2018 General Specifications for Highways (Revision 2 of 2020).

The main contributions of this study include: (1) a comprehensive analysis of the effect of liquid latex on the Marshall parameters of AC-WC mixtures, (2) the determination of the optimum liquid latex content based on laboratory testing, and (3) the provision of scientific references on the use of natural rubber as an additive for sustainable road pavement. The structure of this paper consists of research methods, results and discussion, as well as conclusions and recommendations. In addition to technical considerations, the use of liquid latex as an additive in asphalt mixtures also has important implications from an economic, environmental, and infrastructure development policy perspective. The use of natural rubber-based materials has the potential to increase the added value of national rubber commodities, especially amid fluctuations in natural rubber prices in the global market that tend to be detrimental to farmers [7]. The integration of natural rubber into the road construction sector can be a strategy for diversifying the use of rubber while promoting linkages between the agricultural and infrastructure sectors. From a macroeconomic perspective, this approach is expected to reduce dependence on synthetic polymer-based additives, most of which are still imported, thereby contributing to construction cost efficiency and strengthening the domestic industry [4], [8]. From an environmental perspective, the use of liquid latex as an additive is in line with the concept of sustainable infrastructure development, which emphasizes the use of local and renewable resources. Natural rubber-based additives are considered to have a lower carbon footprint than synthetic polymers and have the potential to increase pavement service life, thereby reducing the frequency of road maintenance [10].

2. Literature Review

Road Pavement

Road pavement is the uppermost structural part of a road structure designed to safely receive and distribute vehicle loads to the subgrade. This pavement is formed from materials with specific characteristics that take into account aspects of thickness, strength, and stability in order to function optimally throughout its planned lifespan [4]. According to Sukirman, pavement construction can be classified into three types based on the binding material, namely flexible pavement, rigid pavement, and composite pavement. Each type of pavement has different structural characteristics and responses to traffic loads and environmental conditions.

Asphalt Concrete Layer

Asphalt concrete (laston) is a type of flexible pavement composed of a mixture of aggregates, asphalt as a binding material, and certain additives that are mixed homogeneously at high temperatures in an asphalt mixing plant (AMP). The mixture is then transported to the work site to be spread and compacted to form a dense and continuous pavement layer [6]. Asphalt concrete layers are designed to have an adequate level of stability to withstand heavy traffic loads and have good resistance to temperature variations and extreme weather conditions [7]. In addition to these advantages, asphalt concrete layers also have limitations, particularly sensitivity to changes in asphalt content and aggregate gradation. Inaccuracies in the mixture composition can trigger premature damage such as cracks or permanent deformation on the road surface. In pavement structures, asphalt concrete is classified into three types based on its function, namely AC-WC as a surface layer, AC-BC as a binder layer, and AC-Base as a foundation layer. AC-WC has a maximum aggregate size of 19 mm with a minimum thickness of 4 cm, while AC-BC and AC-Base use larger aggregate sizes and thicknesses according to their functions [6]. According to Sukirman [6], the performance of asphalt concrete layers is determined by several main characteristics, including stability against permanent deformation, durability in facing traffic loads and environmental influences, flexibility to adjust to changes in the underlying layers, surface roughness to ensure traffic safety, resistance to fatigue due to repeated loads, waterproof properties, and ease of mixing, paving, and compaction.

Latex as an Asphalt Additive

Latex is a natural sap produced by rubber trees (Hevea brasiliensis) through a process of tapping the trunk. Fresh latex is a white, milk-like liquid that has not undergone coagulation, either naturally or through specific chemical treatment [8]. As one of the world's largest rubber producers, Indonesia has an abundant supply of latex that has the potential to be utilized in the road construction sector. The use of liquid latex as an additive in asphalt mixtures is considered to improve pavement performance, particularly in reducing deformation, increasing crack resistance, and improving the adhesion between asphalt and aggregates [3]. In order to be used as an additive, latex must meet certain quality requirements, such as being free of impurities, not mixed with water or latex serum, having a clean white color with a distinctive fresh rubber aroma, and having a dry rubber content ranging from 20% to 28% [9]. During the mixing process with hot asphalt, the rubber particles in the latex will disperse and interact physically and mechanically with the asphalt, forming a mixture that is more plastic and elastic. This condition produces rubber asphalt with better flexibility and deformation resistance compared to conventional asphalt [10]. However, latex also has weaknesses, especially its susceptibility to oxidation and degradation due to ozone exposure, which is caused by the presence of double bonds in the natural rubber molecular structure [11].

Marshall Characteristics

Marshall characteristics are a set of parameters used to assess the performance and behavior of asphalt mixtures in road pavement construction through laboratory testing using a Marshall Compression Machine. These parameters describe the volumetric and mechanical properties of asphalt mixtures so that they can be used as a basis for evaluating the suitability of mixtures for applicable technical requirements [4]. The Marshall characteristics that are commonly analyzed include:

Density

Density indicates the degree of compactness of the mixture between the aggregate and asphalt in a given unit of volume. The density value is influenced by the aggregate gradation, the quality of the constituent materials, and the compaction process, which includes the compaction temperature, number of blows, asphalt content, and the use of additives.

Stability

Stability describes the ability of the asphalt mixture to withstand traffic loads without undergoing permanent deformation, such as rutting or bleeding. The stability value generally increases with increasing asphalt content until it reaches an optimum value, then decreases when the asphalt content is excessive due to a reduction in the stiffness of the mixture. Stability is expressed in kilograms (kg), with a minimum required value of 800 kg according to the 2018 Revised General Specifications for Highways.

Flow

Flow is the amount of vertical deformation of the asphalt mixture when it reaches maximum stability before load reduction occurs. This parameter reflects the elasticity of the mixture and is expressed in units of 0.01 mm. Based on the 2018 Revised General Specifications for Road Construction, the permissible flow value is in the range of 2–4 mm.

Void in Mix (VIM)

VIM indicates the percentage of air void volume in the asphalt mixture. An excessively high VIM value indicates high porosity, which can accelerate the oxidation process and reduce the bonding strength between particles. The 2018 Revised General Specifications for Road Construction requires the VIM value to be in the range of 3%–5%.

Void in Mineral Aggregate (VMA)

VMA is the percentage of empty space between aggregate particles that can be filled by asphalt and air relative to the total volume of the mixture. An adequate VMA value is necessary to ensure sufficient asphalt in the mixture. The minimum VMA value required is 15% according to the 2018 Revision 2 General Specifications for Highways.

Void Filled with Asphalt (VFA)

VFA indicates the percentage of aggregate voids filled with asphalt. An excessively high VFA value can cause bleeding, while an excessively low value has the potential to reduce the mixture's resistance to the effects of water. The minimum VFA value required is 65% based on the 2018 Revised General Specifications for Road Construction.

Marshall Quotient (MQ)

The Marshall Quotient is the ratio between the stability and flow values, reflecting the balance between the stiffness and elasticity of the asphalt mixture. A low MQ value indicates that the mixture tends to be soft and susceptible to permanent deformation. The 2018 Revised General Specifications for Road Construction requires a minimum MQ value of 250 kg/mm.

3. Research Method

This study employed a laboratory experimental method to analyze the effect of liquid latex addition on the Marshall characteristics of Asphalt Concrete–Wearing Course (AC-WC) mixtures. The mix design and all testing procedures were conducted in accordance with the 2018 General Specifications for Road Construction and Bridges (Revision 2 of 2020) issued by the Directorate General of Highways. Five variations of liquid latex content were used, namely 0%, 2.5%, 5%, 7.5%, and 10% by weight of asphalt, with three specimens prepared for each variation, resulting in a total of 15 test specimens. The Job Mix Formula (JMF) applied in this research was obtained from the laboratory of PT. Perwita Konstruksi Cirebon.

Data collection consisted of primary and secondary data. Primary data were obtained through laboratory testing, including tests of aggregate physical properties, asphalt physical properties, and Marshall testing of AC-WC mixtures to determine stability, flow, density, Voids in Mix (VIM), Voids in Mineral Aggregate (VMA), Voids Filled with Asphalt (VFA), and Marshall Quotient (MQ). Secondary data were obtained from technical standards, specification documents, and relevant previous studies to support the analysis and discussion.

Aggregate and asphalt physical property tests were conducted at the Civil Engineering Laboratory of Universitas Pancasakti Tegal, while specimen preparation and Marshall testing were performed at the laboratory of PT. Perwita Konstruksi Cirebon. All tests were carried out in accordance with applicable Indonesian National Standards and relevant technical specifications.

The experimental results were processed and analyzed using Microsoft Excel software through descriptive and comparative analysis. This analysis aimed to evaluate the influence of liquid latex content on the Marshall characteristics of AC-WC mixtures and to determine the optimum liquid latex content that satisfies technical requirements. The findings are expected to provide practical recommendations for the implementation of liquid latex as an additive in asphalt pavement construction.

4. Results and Discussion

Aggregate testing aims to ensure that the quality of the materials used complies with road pavement standards. In this test, all aggregate samples tested were obtained from AMP PT. Perwita Konstruksi Cirebon. This aggregate testing included testing the specific gravity and water absorption of the aggregate, aggregate sieve analysis, and aggregate wear. The results of the aggregate testing are presented in the following table.

Table 1. Results of Coarse Aggregate Testing (0-5 mm Aggregate).

No.	Type Of Test	Method	Spesification	Result	Remarks
1.	Bulk Density (gr/cc)	SNI 1969:2016	Min. 2,5	2,665	Compliant
2.	SSD Density (gr/cc)	SNI 1969:2016	Min. 2,5	2,696	Compliant
3.	*Apparent Specific Gravity* (gr/cc)	SNI 1969:2016	Min. 2,5	2,749	Compliant
4.	Water Absorption (%)	SNI 1969:2016	Max. 3	1,15	Compliant
5.	Aggregate Wear (%)	SNI 2417:2008	Max. 40	24	Compliant

Table 2. Results of Coarse Aggregate Testing (10-20 mm Aggregate).

No.	Type Of Test	Method	Spesification	Result	Remarks
1.	Bulk Density (gr/cc)	SNI 1969:2016	Min. 2,5	2,634	Compliant
2.	SSD Density (gr/cc)	SNI 1969:2016	Min. 2,5	2,657	Compliant
3.	Apparent Specific Gravity (gr/cc)	SNI 1969:2016	Min. 2,5	2,695	Compliant
4.	Water Absorption (%)	SNI 1969:2016	Max. 3	0,854	Compliant
5.	Aggregate Wear (%)	SNI 2417:2008	Max. 40	24	Compliant

Table 3. Fine Aggregate (Stone Ash) Test Results.

No.	Type Of Test	Method	Spesification	Result	Remarks
1.	Bulk Density (gr/cc)	SNI 1969:2016	Min. 2,5	2,567	Compliant
2.	SSD Density (gr/cc)	SNI 1969:2016	Min. 2,5	2,615	Compliant
3.	Apparent Specific Gravity (gr/cc)	SNI 1969:2016	Min. 2,5	2,707	Compliant
4.	Water Absorption (%)	SNI 1969:2016	Max. 3	2,135	Compliant

Table 4. Filler (Cement) Test Results.

No.	Type Of Test	Method	Spesification	Result	Remarks
1.	Bulk Density (gr/cc)	SNI 03-2531-1991	3 - 3,2	2,567	Compliant
2.	SSD Density (gr/cc)	SNI 03-2531-1991	3 - 3,2	2,615	Compliant
3.	Apparent Specific Gravity (gr/cc)	SNI 03-2531-1991	3 - 3,2	2,707	Compliant
4.	Water Absorption (%)	SNI 03-2531-1991	3 - 3,2	2,135	Compliant

Asphalt Test Results

Asphalt testing aims to ensure that the quality of asphalt materials complies with road pavement standards and to determine the physical and chemical characteristics of asphalt. In this test, 60/70 penetration asphalt obtained from AMP PT. Perwita Konstruksi Cirebon was used.

Table 5. Asphalt Test Results.

No.	Type Of Test	Method	Spesification	Result	Remarks
1.	**Penetration (0,1 mm)**	**SNI 2456:2011**	**60 - 70**	**64,1**	**Compliant**
2.	**Density (gr/cc)**	**SNI 2441:2011**	**≥ 1**	**1,032**	**Compliant**

Job Mix Design

Job Mix Design is the stage of planning the road pavement mix to determine the combination of materials (aggregate, asphalt, filler, and additives) to meet the specified technical specifications. In this study, Job Mix Design data was obtained from AMP PT. Perwita Konstruksi Cirebon, which included Job Mix 100% material data and detailed mix proportions as a reference in making test specimens. The stages of Job Mix Design implementation are as follows:

Determining the Aggregate Gradation Combination

The aggregate gradation combination is determined using the trial and error method, which involves trying various percentages of each aggregate fraction until a mixture gradation within the specified limits is obtained.

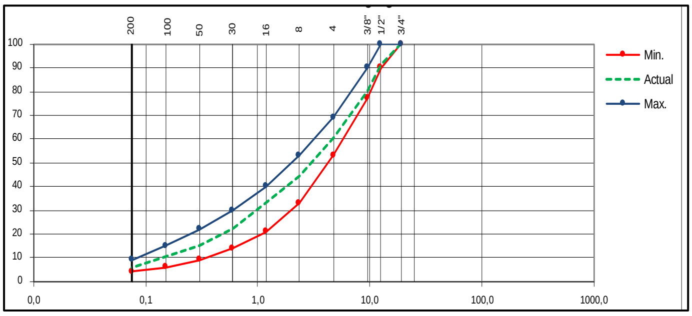

Figure 1. Laston AC-WC Aggregate Combination Chart.

Determining Asphalt Content

Asphalt content is the amount of effective asphalt that coats and fills the voids between aggregate particles. In the laboratory mix design process, the estimated asphalt content (Pb) value is used for each liquid latex variation as follows:

Table 6. Asphalt Content of Liquid Latex Variations.

No.	Variations in Liquid Latex (%)	Asphalt Content (%)
1.	**0**	**6,80**
2.	**2,5**	**6,65**
3.	**5**	**6,51**
4.	**7,5**	**6,37**
5.	**10**	**6,22**

Determine the Mixture Proportion

Determining the mixture proportions begins with calculating the total weight of the materials used. Next, all materials are dried by heating to remove moisture content, then weighed in dry conditions. Based on the dry weight, the amount of asphalt and liquid latex to be mixed can be calculated. The results of the mixture proportion calculations are presented in the following table:

No.	Jenis Material	Job Mix 100% Material	Proporsi Berat Campuran (Gram)														
			Aspal 5,8% Lateks 0%			Aspal 5,65% Lateks 2,5%			Aspal 5,51% Lateks 5%			Aspal 5,37% Lateks 7,5%			Aspal 5,22% Lateks 10%		
		Kombinasi	I	II	III	I	II	III	I	II	III	I	II	III	I	II	III
1	Agregat Kasar (CA)	9%	97,5			97,7			97,8			97,9			98,1		
2	Agregat Sedang (MA)	35%	379,2			379,8			380,3			380,9			381,5		
3	Abu Batu (FA)	55%	595,8			596,8			597,6			598,5			599,5		
4	Filler (Semen)	1%	10,8			10,9			10,9			10,9			10,9		
Jumlah		**100%**															
Berat Kumulatif Material (Gr)			1083,3			1085,2			1086,6			1088,2			1090,0		
Berat Kering Material (Gr)			1074	1076	1080	1081	1076	1074	1078	1075	1078	1079	1079	1075	1080	1081	1075
Berat Aspal (Gr)			66			64			63			61			59		
Berat Lateks Cair (Gr)			-			2			4			5			7		
Berat Total Campuran (Gr)			1140	1142	1146	1148	1142	1140	1145	1142	1145	1145	1145	1141	1146	1147	1141

Figure 2. Results of Mixture Proportion Calculations.

Marshall Test Results

Based on the Marshall test results, the effect of using liquid latex as an additive in AC-WC asphalt mixtures on Marshall characteristics and the variation of liquid latex with the best performance can be determined as follows:

Effect of Using Liquid Latex as an Additive on Marshall Characteristics

Tabel 7. Stability Test Results.

No.	Variations in Liquid Latex (%)	Stability (kg)
1.	0	1033,6
2.	2,5	1102,2
3.	5	1088,5
4.	7,5	841,5
5.	10	823,2

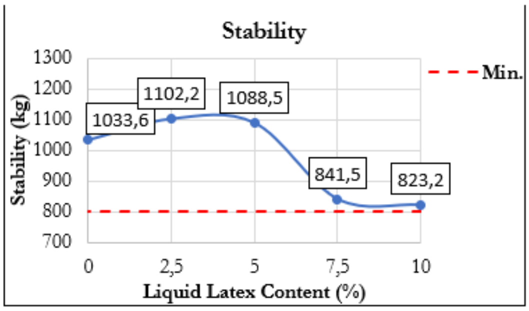

Figure 3. Graph of the Relationship Between Liquid Latex Content and Stability.

The graph shows that adding liquid latex up to a content of 2.5% significantly increases the stability of the mixture, with a maximum value of 1102.2 kg. At this content, latex has a positive effect on the cohesion and binding power of the mixture. However, after this content, stability begins to decline. At a concentration of 5%, stability drops to 1088.5 kg, then decreases dramatically at a concentration of 7.5% to 841.5 kg, and continues to decrease to 823.2 kg at a concentration of 10%. Nevertheless, all stability values remain above the minimum limit of 800 kg as specified in the 2018 Revised General Specifications for Road Construction for AC-WC asphalt.

Effect of Liquid Latex Addition on Flow

Table 8. Flow Test Results.

No.	Variations in Liquid Latex (%)	*Flow* (mm)
1.	0	2,96
2.	2,5	3,13
3.	5	3,73
4.	7,5	4,74
5.	10	3,72

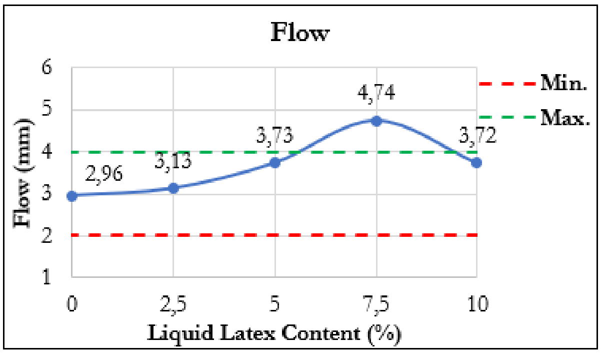

Figure 4. Graph showing the relationship between liquid latex cadres and flow.

Based on the 2018 Revised General Specifications for Road Construction, the permissible flow value limit for AC-WC asphalt is 2-4 mm. The graph shows that the addition of liquid latex has a significant effect on the flow value. In mixtures without latex (0%), the flow value was recorded at 2.96 mm and increased to 3.13 mm at a concentration of 2.5% and 3.73 mm at a concentration of 5%, both of which are still within the specified limits. The maximum value occurred at a concentration of 7.5%, which was 4.74 mm, exceeding the maximum limit. Meanwhile, at a concentration of 10%, the flow value decreased again to 3.72 mm, returning to within the specified limits.

a. The Effect of Liquid Latex Addition on the Marshall Quotient (MQ)

Tabel 9. Marshall Quotient (MQ) Test Results.

No.	Variations in Liquid Latex (%)	MQ (kg/mm)
1.	0	354,44
2.	2,5	355,15
3.	5	292,46
4.	7,5	180,11
5.	10	223,57

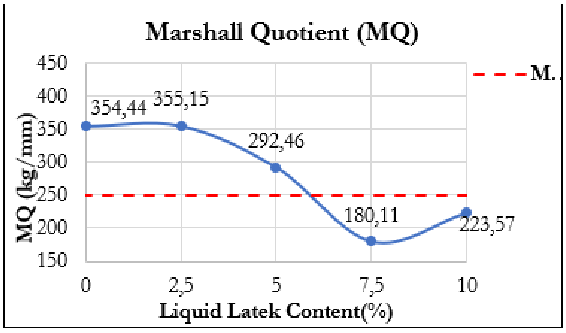

Figure 5. Graph showing the relationship between liquid latex content and MQ.

Based on the 2018 Revised General Specifications for Road Construction, the minimum Marshall Quotient (MQ) value for AC-WC asphalt concrete is 250 kg/mm. The graph shows that the addition of liquid latex affects the decrease in MQ value. At 0% and 2.5% content, the MQ value is relatively high at 354.44 kg/mm and 355.15 kg/mm, indicating that the mixture is still very stiff and stable. The value starts to decrease at 5% content to 292.46 kg/mm, but is still within the permissible limits. A significant decrease occurs at a concentration of 7.5% with an MQ value of 180.11 kg/mm, which is below the minimum limit. Meanwhile, at a concentration of 10%, the MQ value increases slightly to 223.57 kg/mm, but still does not meet the standard.

b. Effect of Liquid Latex Addition on VIM

Tabel 10. Result VIM.

No.	Liquid Latek Variation (%)	VIM (%)
1.	0	3,43
2.	2,5	3,87
3.	5	1,34
4.	7,5	5,71
5.	10	7,29

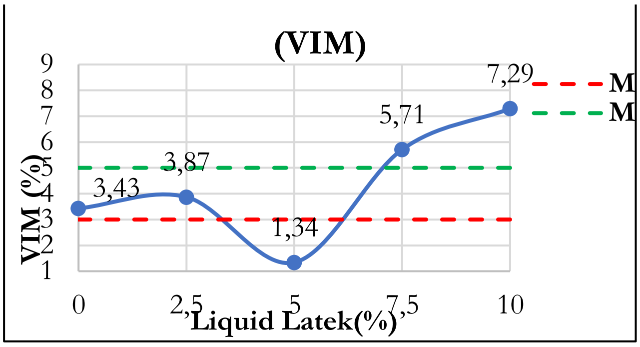

Figure 6. Graph of the Relationship Between Liquid Latex Content and VIM.

Based on the 2018 Revised General Specifications for Road Construction, the VIM value for AC-WC asphalt must be between 3-5%. The graph shows fluctuations in the VIM value due to the addition of liquid latex. At concentrations of 0% and 2.5%, the VIM value is still ideal at 3.43% and 3.87%. However, at a concentration of 5%, it drops dramatically to 1.34%, indicating that the mixture is too dense and at risk of bleeding. Conversely, at concentrations of 7.5% and 10%, the VIM value increases significantly to 5.71% and 7.29%, exceeding the maximum limit, indicating that the mixture is too porous and susceptible to damage from water and traffic loads.

c. The Effect of Liquid Latex Addition on VFA

Table 11. Result VMA.

No.	Liquid Latek (%)	VMA (%)
1.	0	18,16
2.	2,5	17,01
3.	5	17,03
4.	7,5	18,16
5.	10	18,93

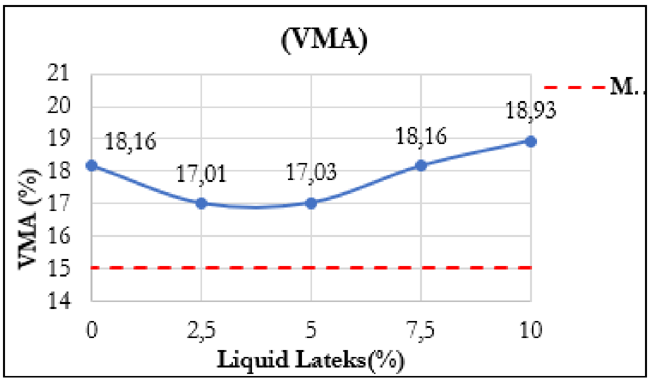

Figure 7. Graph of the Relationship Between Liquid Latex Content and VIM.

Based on the 2018 Revised General Specifications for Road Construction, the minimum VMA value for AC-WC asphalt is 15%. The graph shows that all VMA values at varying liquid latex content are above this minimum limit. At 0% content, the VMA value was recorded at 18.16% and decreased to 17.01% at 2.5% content and 17.03% at 5% content. At a concentration of 7.5%, the VMA value increased again to 18.16% and reached its highest value at a concentration of 10% at 18.93%. This increase indicates the formation of larger voids due to changes in the aggregate structure, possibly influenced by the elasticity of the liquid latex, which alters the density of the mixture.

d. The Effect of Liquid Latex Addition on VFA

Tabel 12. Result VFA.

No.	Liquid Latek Var (%)	VFA (%)
1.	0	81,13
2.	2,5	77,26
3.	5	92,10
4.	7,5	68,67
5.	10	61,51

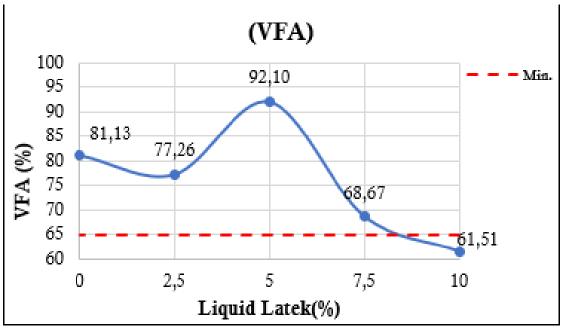

Figure 8. Graph of the Relationship Between Liquid Latex Content and VFA.

Based on the 2018 Revised General Specifications for Road Construction, the minimum VFA value for AC-WC asphalt is 65%. The graph shows fluctuations in VFA values due to the addition of liquid latex. At a content of 0%, the VFA value was recorded at 81.13% and decreased to 77.26% at a content of 2.5%. A significant increase occurred at a concentration of 5% to 92.10%, indicating that the asphalt was able to fill the aggregate voids to the maximum extent, which could increase the binding power of the mixture. However, at a concentration of 7.5%, there was a significant decrease to 68.67% and continued to decline to 61.51% at a concentration of 10%, where the VFA value was below the specified minimum limit.

e. Effect of Liquid Latex Addition on Density

Table 13. test results.

No.	Liquid Latek Variation (%)	*Density* (gr/cc)
1.	0	2,268
2.	2,5	2,297
3.	5	2,293
4.	7,5	2,258
5.	10	2,233

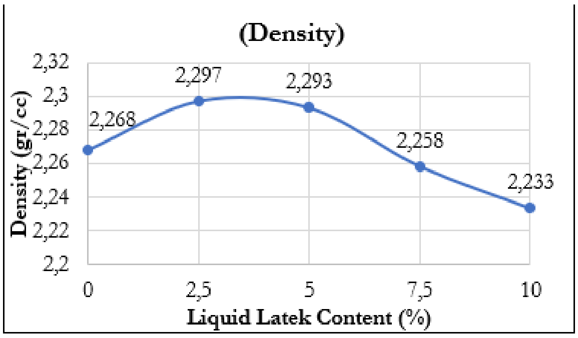

Figure 9. Graph of the Relationship Between Liquid Latex Content and Density.

The graph shows that adding liquid latex up to a content of 2.5% increases the density value of the mixture, with the highest value being 2.297 g/cc. However, at a content of 5%, the density value decreases slightly to 2.293 g/cc, then continues to decrease. decreased to 2.258 g/cc at a concentration of 7.5% and reached 2.233 g/cc at a concentration of 10%.

This indicates that the addition of liquid latex can reduce density due to the formation of voids or changes in distribution within the material.

Identification of the Best Performing Liquid Latex Variation

The determination of the best-performing liquid latex variation is based on a comparison of all Marshall characteristic results against the provisions of the 2018 Revised General Specifications for Road Construction, as well as considering the overall consistency of the mixture. The results of the Marshall characteristic testing are presented in the following table.

Table 14. Marshall Test Results.

No.	Marshall Characteristics	Specifications	Variations of Liquid Latex				
			0%	2,5%	5%	7,5%	10%
1.	Stability (kg)	Min. 800	1033,6	1102,2	1088,5	841,5	823,2
2.	*Flow* (mm)	2 - 4	2,96	3,13	3,73	4,74	3,72
3.	*Marshall Quotient* (kg/mm)	Min. 250	354,44	355,15	292,46	180,11	223,57
4.	VIM (%)	3 – 5	3,43	3,87	1,34	5,71	7,29
5.	VMA (%)	Min. 15	18,16	17,01	17,03	18,16	18,93
6.	VFA (%)	Min. 65	81,13	77,26	92,10	68,67	61,51
7.	*Density* (gr/cc)	-	2,268	2,297	2,293	2,258	2,233

Based on the results of testing the Marshall characteristics of AC-WC asphalt mixes with the addition of liquid latex in variations of 2.5%, 5%, 7.5%, and 10%, it was found that a 2.5% variation of liquid latex produced the best performance compared to the other variations. This is because the 2.5% liquid latex variation produced the highest stability value of 1102.2 kg, flow of 3.13 mm, VIM of 3.87%, VMA of 17.01%, VFA of 77.26%, Marshall Quotient (MQ) of 355.15 kg/mm, and density of 2.297 g/cc, where all Marshall characteristic values meet the requirements of the 2018 Revised General Specifications for Public Works for AC-WC asphalt.

These results reflect that at a concentration of 2.5%, liquid latex is able to improve the cohesion and stiffness of the mixture in a balanced manner without sacrificing flexibility or disrupting the pore structure in the asphalt mixture.

5. Conclusion

Based on the results of the study, it can be concluded that: The addition of liquid latex at levels of 2.5%, 5%, 7.5%, and 10% has a significant effect on Marshall characteristics such as stability, flow, Marshall Quotient (MQ), VIM, VMA, VFA, and density. Adding a specific amount, namely 2.5%, can improve the overall quality of the asphalt mixture, while adding more than that actually reduces the performance of the mixture. Overall, liquid latex can improve the cohesion and density of the mixture, but excessive use can reduce the stability and stiffness of the structure. A variation in the addition of 2.5% liquid latex to the AC-WC asphalt mixture produced the best performance and met all Marshall characteristics in accordance with the 2018 Revised General Specifications for Highways. At this level, with an asphalt content of 5.65%, a stability value of 1102.2 kg, flow of 3.13 mm, VIM of 3.87%, VMA of 17.01%, VFA of 77.26%, MQ of 355.15 kg/mm, and density of 2.297 g/cc were obtained.

Recommendations

Several recommendations that need to be considered to obtain better results include: It is recommended to determine the optimum asphalt content (OAC) first, since the optimum content of liquid latex is already known. This research is still limited to laboratory scale, so field tests are needed to assess the performance and durability of the mixture under actual conditions. In the process of making test specimens, it is expected that more care will be taken, especially at the stage of heating and compacting the mixture to ensure consistency in the test results. Further research can be conducted by varying the types of latex and filler in other asphalt pavement mixtures.

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