

# The Effect of Natural Rubber Modification on Asphalt Mixture Performance Based on Marshall Test Results

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## ABSTRACT

Pavement damage is caused by low asphalt quality, asphalt content, road support structures, and compaction not in accordance with existing specifications or standards. To overcome these problems, innovation is needed to make an asphalt mixture for road pavement. The use of natural rubber-based rubber asphalt as an additive to asphalt concrete has long been used. This study aims to determine the effect of the use of natural rubber in an asphalt penetration grade 60/70 mixture and to determine the results of Marshall tests based on the mixture performance for each Marshall parameter, such as stability, flow, density, volumetric analysis, namely VIM, VMA, VFB, and the Marshall quotient. Marshall tests were conducted on several natural rubber concentrations (1%, 2%, 3%, 4%, and 5%) to determine the optimum asphalt content of the natural rubber asphalt mixture. The results of the study showed that mixing natural rubber into the asphalt mixture requires special treatment, namely, without a heating phase. The optimum asphalt content value for the natural rubber asphalt mixture is 4% natural rubber and 6% asphalt.

*Keywords-asphalt; marshall test; natural rubber; road pavement*

## I. INTRODUCTION

Road infrastructure is a means of land transportation that supports various needs and logistics distribution, thereby increasing economic growth. Indonesia's population growth could lead to road damage due to heavier vehicle loads and higher traffic speeds. Road damage can negatively affect road users, leading to congestion, traffic accidents, and longer travel times to reach their destinations [1]. Road infrastructure in Indonesia remains a critical concern for the government, particularly given the high rate of damaged roads. As reported in 2022, approximately 179,000 kilometers, or 31.9% of roads across the country, were in damaged condition, with 15.9% classified as severely damaged. Among the total 440,000 kilometers of damaged roads, 46.85% were provincial roads [2].

Damage to road pavements is generally in the form of road cracks, uneven asphalt concrete surfaces, and disturbing potholes. Damage can be caused by various factors, such as failure of the road support structure, a mismatch in asphalt

content, improper mixing temperature, low-quality asphalt, a compaction process that does not meet specifications or standards, and inadequate asphalt viscosity. This damage renders the road unable to withstand heat exposure and susceptible to waterlogging [3]. Natural rubber has significant potential for use in asphalt mixtures as a substitute for imported synthetic polymers. Natural rubber also has excellent elasticity, high plasticity, and strong adhesion, which increases the tensile strength of asphalt when stretched. The addition of natural rubber to conventional asphalt can increase its flexibility and resistance to damage [4, 5]. Natural rubber technology as a mixed material in asphalt has been developed and applied in recent innovations to minimize damage to road pavements [6,7].

Indonesia is the second-largest rubber-producing country, with production reaching 3.37 million tons in 2020. The use of natural rubber in Indonesia remains very low due to fluctuating prices, making it less profitable to trade as a commodity. Therefore, the potential of rubber must be utilized or managed optimally to produce competitive goods or rubber products. One

way to increase added value is by making natural rubber an additive in road construction. The use of natural rubber can also be a solution to encourage domestic consumption, while also potentially helping restore natural rubber prices in the international market [8].

Polymer Modified Asphalt (PMA) based on natural rubber is one innovation with strong potential to help achieve the government's target for natural-rubber utilization and to stimulate demand. In Indonesia, large-scale implementation of rubber asphalt is projected to absorb around 60,000 tons of natural rubber, depending on adoption across national and provincial networks [9]. Compared with conventional asphalt, rubber asphalt better withstands deformation (e.g., rutting grooves or depressions formed by heavy wheel loads), limits peeling/stripping of the asphalt film from the aggregate, and exhibits greater resistance to cracking under environmental temperature fluctuations [10]. At the binder level, Authors in [11] reported that modification with 3.2% latex by weight of asphalt yields a well-distributed additive and significantly increases the softening point and Brookfield viscosity, indicators of improved high-temperature performance, while, as also shown in related work, latex addition reduces penetration in the original asphalt, reflecting a stiffer and more deformation-resistant binder [12,13].

Research on the development of natural rubber as an additive in asphalt mixtures shows that natural rubber can increase the binding power between molecules. Asphalt mixtures with natural rubber additives can also improve asphalt quality, including high flexibility, resistance to temperature-induced deformation, optimal resilient modulus, resistance to wear, and improved resistance to water seepage [14]. The addition of latex to 60/70 penetration asphalt can increase the softening point of asphalt and recovery value but reduce its penetration value. Previous studies show that adding 19% latex concentrate can be used as a filler in flexible pavement cracks. Still, the addition of excessive latex will reduce the workability as a crack filler [15]. However, several studies have examined the performance of asphalt modified with lower concentrations of rubber, which remain largely untested. Therefore, this study aims to address this gap by investigating the effects of incorporating smaller, more detailed percentages of natural rubber (i.e., 1%–5%) into asphalt mixtures. Natural rubber affects the Marshall Quotient (MQ), which is the ratio of stability to flow. MQ is used to evaluate the stiffness of asphalt mixtures; the interaction results show that asphalt, latex, and the interaction between asphalt and latex show significant results. The asphalt mixture, after being mixed with additives, meets applicable standards. The best result is for flexible pavement Type A, with a latex content of 3%, and it can be recommended in [16].

Based on the description, the importance of this study is to determine the effect of adding natural rubber to a 60/70 penetration asphalt mixture on Marshall characteristics; to determine the Marshall characteristic values of adding natural rubber as a mixture in 60/70 penetration asphalt that meets the mixing requirements; and to determine the comparison between 60/70 penetration asphalt with a mixture of natural rubber and 60/70 penetration asphalt without a mixture of natural rubber.

## II. MATERIALS AND METHODS

### A. Asphalt Cement

The asphalt cement utilized in this study is 60-70 penetration grade. It is commonly used in road construction and in the production of asphalt pavement in Indonesia. The test results of asphalt characteristics are portrayed in Table I.

TABLE I. ASPHALT CHARACTERISTIC TEST RESULT

Property	Test method	Penetration grade 60/70	
		Result	Specification
Penetration at 25°C (0.1mm)	SNI 2456: 2011	62	60-70
Viscosity (°C)	AASHTO T-72-90	155	-
Specific gravity of asphalt (gr/cc)	SNI 2441: 2011	1.029	≥ 1.0
Softening point (°C)	SNI 2434: 2011	51.23	≥ 48
Flash point (°C)	SNI 2433: 2011	285	-
Ductility on 25 °C (cm)	SNI 2432:2011	132.25	≥ 100
Lose weight	SNI 06-2440-1991	0.751	≤ 0.8

### B. Fine and Coarse Aggregates

The coarse and fine aggregates were sieved and recombined in specific proportions to meet the wearing course gradation requirements specified by Bina Marga [23]. Aggregate gradation is one of the characteristics that affect pavement strength [17]. The aggregate gradation value is obtained from the percentage of each aggregate that passes through sieves No. 1 to No. 200, consisting of 1/1 stone material, 1/2 stone, sand, and stone ash. The surface layer for the wearing course utilized crushed coarse aggregates (4.75–19 mm) and fine aggregates (passing the No. 4–No. 200 sieves). The aggregate gradation curve is presented in Figure 1 and numerically provided in Table II. To assess the physical properties and characteristics of the aggregates, several tests were conducted. The test results, with the specification set of Bina Marga, are given in Table III and Table IV. The test results confirm that the aggregates meet Bina Marga specifications.

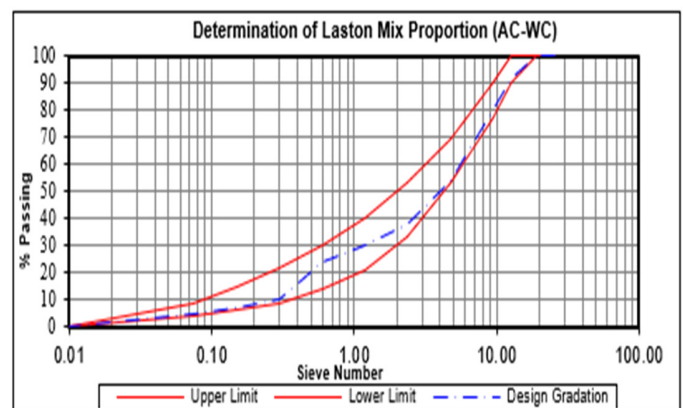


Fig. 1. Aggregates gradation chart.

TABLE II. AGGREGATE GRADATION

Sieve size		Passing	
		Gradation	Specification
inci / no	(mm)	(%)	(%)
1"	25.400	100	100
3/4 "	19.050	100	100
1/2 "	12.700	91.88	90 - 100
3/8"	9.525	80.20	77 - 90
# 4	4.750	53.69	53 - 69
# 8	2.360	37.72	33 - 53
# 16	1.200	30.12	21 - 40
# 30	0.600	24.19	14 - 30
# 50	0.300	10.48	9 - 22
# 100	0.150	7.29	6 - 15
# 200	0.075	5.18	4 - 9

TABLE III. PHYSICAL PROPERTIES OF COARSE AGGREGATE

Property	Test method	Result	Specification
Specific gravity of bulk (gr/cm <sup>3</sup> )	SNI 1969:2016	2.577	≥ 2.5
Specific gravity of SSD (gr/cm <sup>3</sup> )		2.589	≥ 2.5
Apparent specific gravity (gr/cm <sup>3</sup> )		2.608	≥ 2.5
Absorption (%)		0.467	Max 3%
Aggregate wear - Abration (%)	SNI 2417:2008	26%	Max 30%

TABLE IV. PHYSICAL PROPERTIES OF FINE AGGREGATE

Property	Test method	Result	Specification
Specific gravity of bulk (gr/cm <sup>3</sup> )	SNI 1969:2016	2.651	≥ 2.5
Specific gravity of SSD (gr/cm <sup>3</sup> )		2.695	≥ 2.5
Apparent specific gravity (gr/cm <sup>3</sup> )		2.772	≥ 2.5
Absorption (%)		1.643	Max 3%

C. Natural Rubber

The natural rubber used in this study was sourced from West Kalimantan. The natural rubber used in this study was obtained from West Kalimantan, an area known for its large rubber production. Five variation levels were tested, namely 1%, 2%, 3%, 4%, and 5% of the binder. These levels were chosen based on previous studies that pointed out the importance of finding the right balance in rubber content. For instance, Authors in [18] reported that a 2% addition to asphalt with 60/70 penetration grade achieved the best Marshall parameters. At the same time, authors in [4] showed that a 5% content produced the most favourable results for the same grade. Such findings indicate that the effect of natural rubber is not fixed but depends on the mix's context and conditions.

Figure 2 shows the natural rubber sourced from West Kalimantan before processing and incorporation into the mixtures of this study.



Fig. 2. Natural rubber material utilized in the mixtures.

III. EXPERIMENTAL METHODOLOGY

Experimental activities in this study were carried out at the Highway Laboratory of the Faculty of Engineering, Tanjungpura University, Pontianak City. Experiments were conducted to test the effect of one variable on another. This study used the Marshall test to determine the optimum asphalt content in a mixture of 60/70 penetration asphalt and natural rubber additives with natural rubber contents of 1%, 2%, 3%, 4%, and 5%. The mixture planning for 60/70 penetration asphalt includes five variations in asphalt content, as in the study [19]. Test objects for each variation of asphalt content (60/70 penetration) and natural rubber content were made in three samples each. Thus, the total number of test objects created in this study was 75. Testing on 60/70 penetration asphalt and natural rubber was conducted in accordance with previously published research [4, 14, 18, 20–22].

A. Specimen Preparation

The process of making asphalt mixture samples is carried out by mixing aggregates, heating aggregates, adding 60/70 penetration asphalt and natural rubber, and ending with sample compaction. When adding natural rubber, it must not be mixed with penetration asphalt under hot conditions. When the asphalt is hot, it can damage the natural rubber, causing it to harden and clump, as shown in Figure 3.

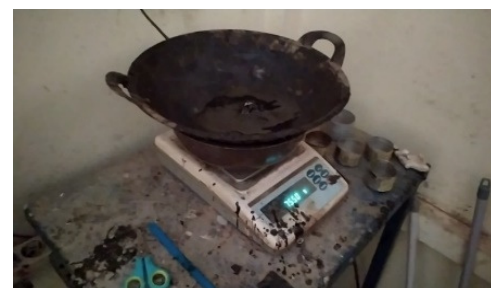


Fig. 3. Natural rubber clumps during the mixing process

Due to these conditions, the process of adding natural rubber is carried out in a special way, where natural rubber does not go through the cooking process and is added before adding 60/70

penetration asphalt to the aggregate, then stirred and cooked again the entire mixture until evenly distributed. In this process, natural rubber can be successfully blended with the mixture, as shown in Figure 4. The specimen mixture will be compacted using cylindrical molds with 75 blows at each end to simulate high traffic conditions.



Fig. 4. Specimen mixing process.

**B. Marshall Test**

This Marshall test follows the procedure as referenced in ASTM D1559 and Bina Marga 2018 Revision 2. This test was implemented to determine the resistance (stability) of the asphalt mixture to plastic deformation (flow) and to determine the optimum asphalt content in pavement mixture through volumetric analysis, namely values such as Void in Mixture (VIM), Void Filled Bitumen (VFB), Void in Mineral Aggregate (VMA), Marshall Quotient (MQ), flow (melting), density and stability [23]. According to the Indonesian Ministry of Public Works and Housing (Bina Marga 2018 Revision 2) [24], the standard requirements for asphalt mixture performance using the Marshall method are presented as follows.

TABLE V. BINA MARGA STANDARD REQUIREMENTS FOR ASPHALT MIXTURE PERFORMANCE

Marshall parameters	Unit	Standard requirement
Marshall stability	kg	≥ 800 kg
Flow (deformation)	mm	2 - 4 mm
Density	-	> 2 gr/cc
VIM	%	3% - 5%
VMA	%	≥ 15%
VFB	%	> 65%
MQ	kg/mm	> 150 kg

Marshall testing is carried out by soaking the test specimens for 24 hours, performing density testing, testing the test object at 60°C, and performing pressure testing using a Marshall test tool. Figure 3 displays photos of specimens during preparation and testing with the Marshall test method.



Fig. 5. Marshall test process.

**IV. RESULTS AND DISCUSSIONS**

Marshall test results were obtained for all variations of natural rubber asphalt mixture specimens on seven Marshall parameters. For each variation of natural rubber asphalt mixture, the optimum asphalt content was determined based on the comparison results of each parameter (stability, flow, density, VIM, VMA, VFB, MQ). The best stability value from the comparisons is the asphalt mixture with 4% natural rubber and 5.5% asphalt pen, with a value of 1,203.43 kg, as shown in Figure 6. The best flow value from the comparison is for the asphalt mixture containing 3% natural rubber and 5% asphalt pen, with a value of 2.43 mm, as shown in Figure 7. The density comparison for each variation of the natural rubber asphalt mixture is shown in Figure 8, with the best density, 2.43 g/cc, for the asphalt mixture containing 4% natural rubber and 7% asphalt pen. Based on Figure 9, the best VIM parameter is the asphalt mixture with 4% natural rubber and 6% asphalt pen, with a value of 3.21%. The best VMA parameter is the asphalt mixture with 2% natural rubber and 5.5% asphalt pen, with a value of 15.93%, as shown in Figure 10. Based on Figure 11, the best VFB is the asphalt mixture containing 4% natural rubber and 5% asphalt pen, with a VFB of 65.54%. Figure 12 shows that natural rubber variations of 1%, 2%, 3%, and 4% have MQ values exceeding 150 kg/mm, which comply with the specification. The best MQ comparison results are for the asphalt mixture with 4% natural rubber and 5.5% asphalt pen, with an MQ value of 460.63 kg/mm.

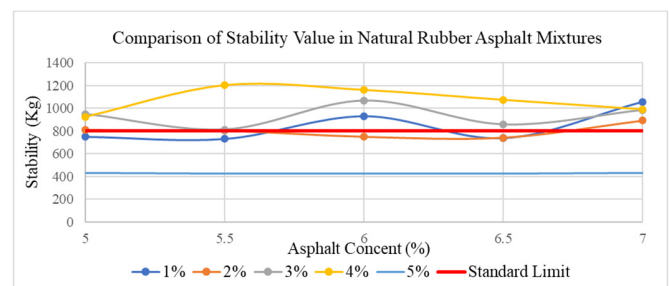


Fig. 6. Stability comparison chart of natural rubber variations.

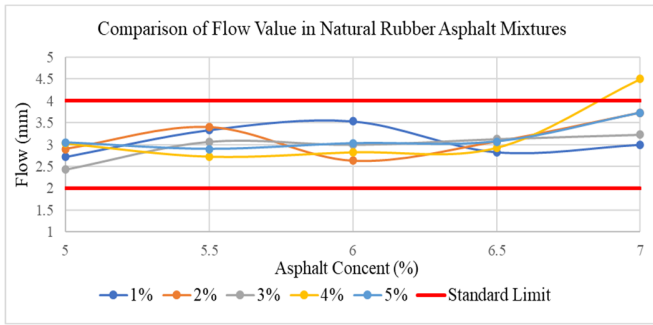


Fig. 7. Flow comparison chart of natural rubber variations.

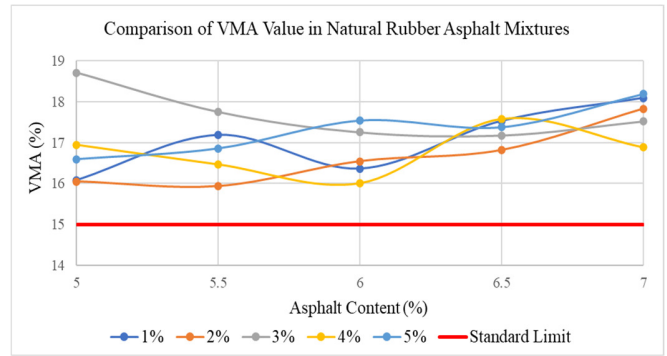


Fig. 10. VMA comparison chart on natural rubber variations.

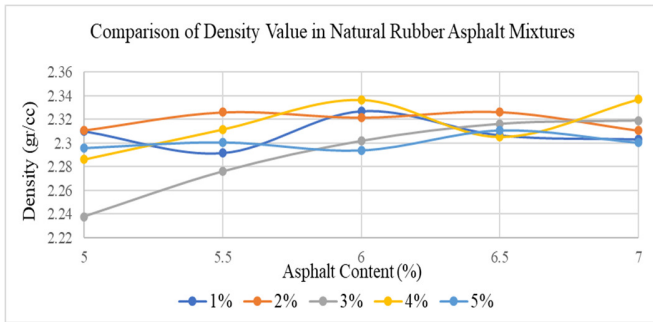


Fig. 8. Density comparison chart of natural rubber variations

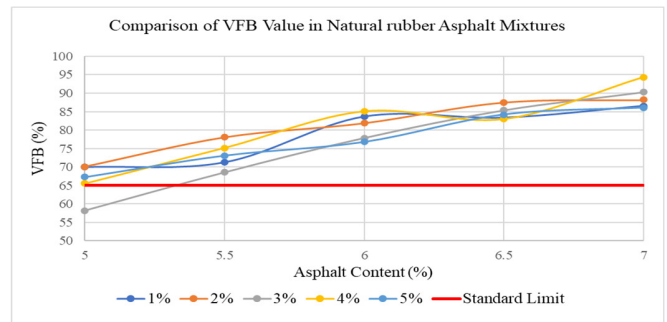


Fig. 11. VFB comparison chart on natural rubber variations.

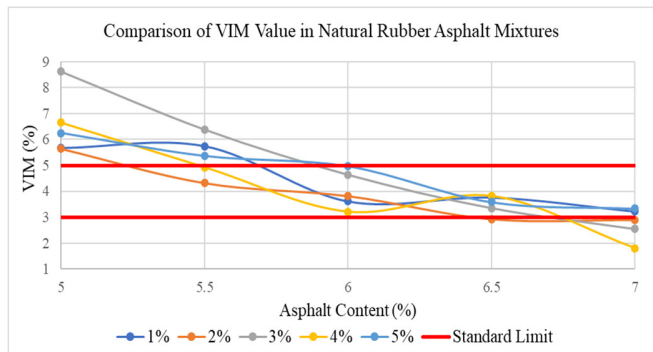


Fig. 9. VIM comparison chart on natural rubber variations.

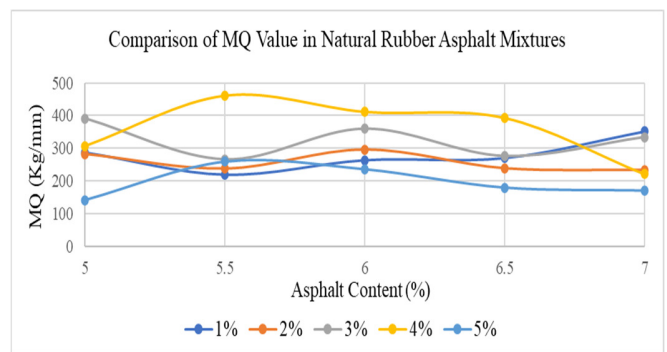


Fig. 12. MQ comparison chart of natural rubber variations.

TABLE VI. COMPARISON OF ALL MARSHALL PARAMETER VALUES

Natural rubber (%)	Asphalt penetration grade 60/70 (%)	Stability (kg)	Flow (mm)	VIM (%)	VMA (%)	VFB (%)	MQ (kg/mm)	Density (gr/cc)
1	6	931.11	3.53	3.61	16.36	83.67	263.87	2.33
	7	1057.73	3.00	3.22	18.09	86.58	351.53	2.30
2	5	811.25	2.90	5.64	16.05	70.07	282.74	2.31
	5.5	803.83	3.40	4.32	15.93	78.05	237.51	2.33
3	6	1068.13	3.00	4.64	17.25	77.87	360.01	2.30
	6.5	857.59	3.13	3.35	17.17	85.38	275.73	2.32
4	5.5	1203.43	2.90	4.93	16.47	75.18	460.63	2.31
	6	1161.17	2.83	3.21	16.01	85.08	411.01	2.34
	6.5	1073.08	2.93	3.82	17.58	82.98	392.48	2.31

Based on Table VI, the results of the comparison of all parameters obtained 9 variations of the mixture that have the best values for each parameter and comply with the Bina Marga Specification standards. The best variation was obtained by an asphalt mixture with 4% natural rubber and 6% asphalt penetration, with the highest and most values in 3 parameters, namely the Flow value of 2.83 mm, the VIM value of 3.21% and the Density value of 2.34 gr/cc as the optimum asphalt content.

## V. CONCLUSION

This study explored the impact of utilizing natural rubber in asphalt mixtures through an experimental method and the Marshall test, providing valuable insights into the performance characteristics of natural rubber asphalt mixtures. The experimental analysis revealed that natural rubber cannot be mixed with penetration asphalt at high temperatures, as high temperatures damage its structure, causing it to harden and clump. To overcome this issue, a special mixing process was developed in which natural rubber is added before introducing the 60/70 grade penetration asphalt to the aggregate, followed by thorough stirring and cooking of the entire mixture to achieve uniform blending. The Marshall test results further showed that the optimum composition for natural rubber asphalt mixtures consists of 6% asphalt and 4% natural rubber, producing the best performance with a Flow value of 2.83 mm, a VIM value of 3.21%, and a density value of 2.34 g/cc. Compared to previous studies, which mainly investigated latex concentrations above 10% and relied on hot-mixing processes, this study expands knowledge by focusing on lower latex contents (1–5%) and validating their performance through Marshall testing. While earlier work, such as [15], reported that higher latex concentrations improved recovery value and softening point but reduced penetration and workability, the present findings demonstrate that lower latex percentages can achieve balanced performance and enhanced applicability. Moreover, adopting a non-thermal mixing process distinguishes this study from conventional approaches, offering advantages in streamlined production, reduced energy consumption, and practical implementation, particularly in tropical regions such as Indonesia.

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