Effect of Tropical Natural Rubber on the Hot Rolled Sheet (HRS) Wearing Course

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Abstract. One effort to improve the performance of road pavement layers and the quality of asphalt mixes is through the modification of asphalt by polymeric materials addition. Latex is a polymer material that can be used and easily found in Indonesia, known as one of the world’s largest natural rubber producer countries. This study intended to improve the quality of Hot Rolled Sheet Wearing Course (HRS-WC) mixture by utilizing latex 1\%, 2\%, 3\%, 4\%, 5\%, 6\%, 7\%, and 8\% as a partial replacement of asphalt material through Marshall testing. From the test results, it can be summarized that the Optimum Asphalt Content (OAC) value of the HRS-WC mixture was 7\%. Furthermore, the Optimum Latex Content (OLC) meeting the specifications was 1\% with a Density value of 2.25, a VMA value of 19.68\%, a VFA value of 76.78\%, a VIM value of 4.57\%, a stability value of 1766.44 kg, a Flow value of 3.14 mm, and MQ value of 629.01 kg/mm

1. Introduction
The highway is one of the essential facilities for the Indonesian people to support various daily activities. In a road structure, pavement layers’ performance is essential. According to Massahi et al.\textsuperscript{[1]}, the road pavement structure must have a strong and durable structural design to prevent structural failure and minimize maintenance costs. Moreover, asphalt and concrete are road pavement materials often used in the structural design process.

Modified asphalt is made by warm aggregate, hot bitumen and additive material \textsuperscript{[2]}\textsuperscript{.} El-Rahman et al. \textsuperscript{[3]} conducted a study by modifying polymer asphalt and concluded that polymer asphalt could improve the performance of asphalt concrete mixtures. Polymer modification could increase the ability of thermal crack resistance, asphalt tensile strength, and permanent deformation resistance and reduce the asphalt temperature susceptibility.

The common aggregates used in road pavement are crushed stones, split stones, and waste material from steel smelting, while the common binder material is asphalt and cement \textsuperscript{[4]}\textsuperscript{.} Road pavement generally consists of three types, rigid, flexible, and composite. In Indonesia, flexible pavement is still the primary choice because it offers optimal comfort for motorists \textsuperscript{[5]}\textsuperscript{.} Hot Rolled Sheet (HRS) is a type of asphalt mixture in the flexible pavement having the characteristic of gap-graded with its constituent materials, namely coarse aggregate, fine aggregate, filler, and a high asphalt content, thus requiring good quality asphalt mixture. Gap gradation is an aggregate gradation in which the aggregate size is incomplete, or there is an aggregate fraction absent or very few. Asphalt mixture with this gradation type has a transition quality between asphalt mixture with uniform-graded and dense-graded. The
relatively high asphalt content of the mixture aims to increase flexibility, durability, and resistance to melting, and reduce susceptibility to cracking [6]. Therefore, to improve the durability of the flexible road pavement layers, it is necessary to modify the asphalt mixture or use polymer asphalt.

According to Pei-Hung [7], polymer asphalt is a mixture of hot asphalt formed from the modification of natural polymer materials or synthetic polymers with pure asphalt material. The interaction between the asphalt and the components of the polymer material is called modified asphalt, expected to improve the properties of the asphalt mixture. Therefore, the integration and compatibility between the polymer additives and asphalt mixture can be achieved. The use of polymers as additive to modify asphalt has continued to develop over the past decade. Besides, polymeric materials and proper mixing methods can improve the quality of the asphalt mixture.

According to Al-Saabaei et al. [8] and Shaffie et al. [9], one method to improve the performance of asphalt is to modify the asphalt using a mixture of latex or natural rubber easily integrated with asphalt material. In cold temperatures, the latex is elastic so it can prevent cracking and, at the same time, maintain the rigidity of the asphalt mixture. During hot weather, latex functions as a binder, which can increase shear forces in the mixture but impact the emergence of bleeding. Therefore, latex can be defined as an elastic hydrocarbon polymer material formed from liquid milky sap obtained by peeling rubber tree bark.

According to Siswanto [10], the use of latex or natural rubber in asphalt mixtures will improve the quality, extend service life, and reduce maintenance costs of road pavement. When the temperature is low, asphalt mixture will become more rigid and easy to cracked. Hence, the latex addition to the asphalt will make the asphalt more elastic and able to accept excessive loads. Nevertheless, at high temperatures, latex will increase the viscosity of an asphalt mixture.

In the process of making homogeneous polymer asphalt modification, the use and mixing of latex with asphalt material are easier than the process of using and mixing asphalt with other polymer materials, due to the presence of dispersed rubber particles; thus the latex can melt quickly with asphalt [11].

According to Wen, et al. [12], the use of natural rubber powder as a bio-modifier and asphalt binding material has shown to have several beneficial effects, including increasing viscosity, restoring elastic properties and potentially increasing pavement resistance to rutting, thermal cracking, and fatigue damage.

This study aimed to determine the effect of the tropical natural rubber utilization on Hot Rolled Sheet mixture and discover the Marshall characteristics of asphalt and latex mixture. HRS mixture is a mixture that uses gaps graded for the aggregate, which decreases the stability of the mixture. Some studies had been conducted to study Hot Rolled Sheet with latex as a additive polimer but so for the further research of as HRS with latex to improve the stability of mixture as a substitute of the binder has not been conducted.

2. Research Method
The latex used in this study served as a substitute for certain portions of asphalt material. Moreover, the specifications used in this study were guidelines from Bina Marga [6]. The testing steps are presented as below.

2.1. Preparation
Coarse aggregate, fine aggregate, asphalt, and latex were the materials used in this study. The maximum nominal size of aggregate used is 1/2 " (12.5mm). The asphalt used was asphalt produced by Pertamina with 60/70 penetration, while coarse and fine aggregates were obtained from Clereng, Kulon Progo. The latex used was in liquid condition. Preparation of tools used to test materials such as coarse aggregate, fine aggregate, asphalt and latex, and testing of Marshall test specimens were confirmed to be in good condition, clean and calibrated.
2.2. Material Testing
The material testing phase was carried out with several predetermined testing methods. Aggregate testing consisted of specific gravity, water absorption, and wear testing (Los Angeles) for coarse aggregates. The testing of modified asphalt involved specific gravity, softening point, penetration, ductility, and oil loss at each percentage of asphalt and latex.

2.3. Mixture Design
In this study, the optimum asphalt content (OAC) was determined in advance by basic testing. Then it was determined that 1%, 2%, 3%, 4%, 5%, 6%, 7%, and 8% were the percentages of latex used as a substitute for a portion of asphalt material. Furthermore, the latex weighted according to a predetermined percentage was put into a container contained asphalt to do the mixing process between asphalt and latex while heated and stirred evenly until the asphalt with latex was evenly mixed.

2.4. Sample Making
At this stage, the aggregate was prepared following the grading analysis plan determined according to the specifications in Table 1. For example, the aggregate retained on a 9.5 mm-size filter was 15% of 1200 grams of combined weight; in other words, its weights were 180 grams. After this step, the aggregate was heated to 165 °C. Then the aggregates mixed with asphalt, which has been added with latex according to the planned percentage, namely 1%, 2%, 3%, 4%, 5%, 6%, 7%, and 8% of asphalt content. The next step was to pound the mixture 2 × 75 times in the mold, and each type of mixing has three samples.

| Filter Size | % Aggregate Weight Passing |
|-------------|----------------------------|
|             | Upper Limit | Lower Limit | Middle Limit | % Retained |
| 19          | 100         | 100         | 100          | 0          |
| 12.5        | 100         | 90          | 95           | 5          |
| 6.3         | 85          | 75          | 80           | 15         |
| 2.36        | 72          | 50          | 61           | 19         |
| 0.6         | 60          | 35          | 47.5         | 13.5       |
| 0.075       | 10          | 6           | 8            | 39.5       |
| Pan         | 8           |             |              |            |
| Total       |             |             |              | 100%       |

2.5. Sample Testing
Marshall Characteristics is a test used as an indicator to find the stability value of a mixture and is a compressive test device equipped with a proving ring, a stability watch, and a flow meter used to measure the flow.

3. Result and Discussion

3.1. Aggregate Test Results
The aggregates tested in this study consisted of fine and coarse aggregates. Tests had been carried out in the form of specific gravity, water absorption, and Los Angeles. The results of aggregate testing are presented in Table 2. In a nutshell, the aggregates used in this study had fulfilled the requirements stipulated in SNI 1969-2008 [13], SNI 1970-2008 [14], and SNI 2417-2008 [15].
3.2. Asphalt and Latex Mixture Test Results

At this stage, asphalt mixtures with latex percentages of 1%, 2%, 3%, 4%, 5%, 6%, 7% and 8% had been tested. The tests consisted of specific gravity, softening point, oil loss, ductility, and penetration tests (see Table 3). The results revealed that the penetration value was decreasing due to the increasing of latex content. It shows that the increase in latex content will increase the asphalt rigidity and rutting resistance [16].

### Table 3. Asphalt test results

| Testing                  | Asphalt Testing Results with latex | Specifications | Standard          |
|--------------------------|-----------------------------------|----------------|-------------------|
|                          | 1%                                | 2%          | 3% | 4% | 5% | 6% | 7% | 8% | Min | Max |                     |
| Specific Gravity         | 1.03                              | 1.03        | 1.03 | 1.04 | 1.04 | 1.03 | 1.06 | 1.03 | ≥ 1                  |                          |
| Softening Point          | 50                                | 49.5        | 55 | 49.5 | 55.5 | 52.5 | 56 | 52.5 | ≥ 48                  | -                        |
| Oil Loss                 | 0.3                               | 0.24        | 0.26 | 0.29 | 0.09 | 0.29 | 0.38 | 0.34 | ≤ 0.8                | SNI 2440-1999[19]        |
| Ductility                | 153                               | 154        | 155.5 | 155 | 156 | 152 | 156 | 154 | 100 | 200                  | SNI 2432-2011[20]        |
| Penetration              | 63.9                              | 63.2        | 62.4 | 60.1 | 58.9 | 58.2 | 51.6 | 50.3 | 50 | 70                  | SNI 2432-2011[20]        |

3.3. Optimum Asphalt Content Testing Results

To determine OAC values, Marshall testing was carried out based on estimates of temporary asphalt percentage with variations in the content of 5.5%, 6%, 6.5%, and 7%. The Bina Marga specifications [6] were used to determine the Optimum Asphalt Content in the mixture. Moreover, the marshall characteristic parameters that should be analyzed were the Density, Stability, Flow, VFA, VMA, and VIM, MQ values based on the SNI 2484-1991 [21]. The results of testing for the Optimum Asphalt Content are presented in Table 4. and Table 5.

### Table 4. Marshall test result

| No | Criteria | Specifications | 5.5% | 6% | 6.5% | 7% |
|----|----------|----------------|------|----|------|----|
| 1  | Density  |                | 2.14 | 2.13 | 2.20 | 2.22 |
| 2  | VMA      | Min 18%        | 22.28 | 22.99 | 20.92 | 20.66 |
| 3  | VFA      | Min 68%        | 50.40 | 52.98 | 65.15 | 73.08 |
| 4  | VIM      | 4-6%           | 11.07 | 10.82 | 7.30 | 5.59 |
| 5  | Stability| Min. 800 Kg    | 958.17 | 903.64 | 1573.58 | 1596.95 |
| 6  | Flow     | Min. 3 mm      | 4.43 | 2.8 | 3 | 3.25 |
| 7  | MQ       | Min. 250 kg/mm | 216.03 | 460.99 | 524.23 | 486.29 |

Based on Table 5, it can be concluded that the optimum asphalt content for the HRS-WC mixture was 7%. This result is obtained from the value of all parameters such as Density, VMA, VIM, VFA, Stability, Flow and MQ into the required specifications.
Table 5. Optimum asphalt content testing results

| No | Criteria      | Specification | Asphalt Content |
|----|---------------|---------------|-----------------|
| 1  | Density       |               | 5.5 6 6.5 7     |
| 2  | VMA           | Min 18%       |                 |
| 3  | VFA           | Min 68%       |                 |
| 4  | VIM           | 4.0-6.0%      |                 |
| 5  | Stability     | Min. 800 Kg   |                 |
| 6  | Flow          | Min. 3        |                 |
| 7  | MQ            | Min. 250 kg/mm|                 |

3.4. Marshall Test Results

3.4.1. Density
Density is the weight of the mixture of pavement layers per unit volume influenced by asphalt content, aggregate quality, the number of collisions made during the compaction step, and the type of asphalt material. The asphalt-latex mixture with a high-density value means that the mixture can withstand higher loads than the asphalt-latex mixture with a low-density value.

Asphalt-latex mixture, which has a non-uniform shape but with high asphalt content, tends to have a relatively higher density value. The relationship of latex percentages with density for each asphalt-latex mixture is presented in Figure 1. Figure 1 shows that the HRS mixture had a greater density along with the higher percentages of latex because the cavities contained in the mixture could be filled with asphalt, thereby the density of HRS mixture became high. These results are in line with Rahmawan’s research [22], concluding that the greater the latex content was, the higher the density value would be because the mixture had a higher density.

3.4.2. Voids in the mineral aggregate (VMA)
VMA is the percentage of air cavities in the aggregate minerals of the asphalt mixture that has been compacted. It also includes the cavities that have been filled with asphalt. The cavity in the aggregate is essential regarding the design of an asphalt mixture because of its nature, which can affect the resistance value of an asphalt mixture. VMA value was used to show the percentage of air cavities in the asphalt mixture caused by the existence of aggregate material having pores. The relationship between latex content and VMA values for each mixture is presented in Figure 2. The analysis results show that a higher latex content in the mixture resulted in a lower VMA value because of the replacement of some asphalt portion with latex material in the HRS mixture, causing the cavities in the aggregate to be filled with asphalt and latex material. The VMA specifications required by Bina Marga [6] was 18%. The test results showed that all of the latex percentage utilization produced the VMA value fulfilling the specifications.

Figure 1. Relationship between the density and the latex content variation in asphalt-latex mixture

Figure 2. Relationship between the VMA and the latex content variation in asphalt-latex mixture
3.4.3. Voids filled with asphalt (VFA)
VFA is a value showing the percentage of the number of pore cavities that can be filled by asphalt binder and latex as a substitute for some asphalt in the HRS mixture. The VFA value can determine the durability value of the HRS mixture. VFA value also indicates the ability of the binding material to wrap the aggregate grains in the asphalt mixture so that they can bind to one another. The relationship between latex content and VFA values for each mixture is presented in Figure 3. The use of higher content of latex as a partial substitute of asphalt material in the HRS mixture increased the VFA value, as seen in Figure 3. This increase occurred because the asphalt-latex mixture could attach and envelope the aggregate granules. Thus, the percentage of cavities in the HRS mixture became low. Moreover, all minimum VFA values obtained were following the specifications used, that is should be greater than 68%.

3.4.4. Voids in the mix (VIM)
VIM is a value stating the percentage of cavities existing between the aggregate grains covered by asphalt in a compacted concrete asphalt mixture. A high VIM value can cause a decrease in the capability of mixture impermeability to water and air that can enter the cavity so that the asphalt becomes easily oxidized, and the bonds between the aggregate grains become weak and cause peeling of the surface layer. Therefore, the VIM value affects the durability value of an HRS mixture. The relationship between latex content with VIM for each mixture is presented in Figure 4. Based on Figure 4, it can be concluded that the higher the latex content in the HRS-WC mixture was, the lower the VIM value would be. The decrease was caused by the cavities in the mixture increasingly filled with a latex material. A low VIM value indicated that the cavity percentage in the mixture was relatively small, meaning that there was not enough space for asphalt, causing the asphalt bleeding under the influence of heavy load and high road surface air temperature. Conversely, a high VIM value would cause the mixture to have less water content and more impermeable. Therefore, the resistance of the HRS mixture became low, and the HRS mixture was more prone to cracks.

![Figure 3](image-url)  [Figure 3. Relationship between the VFA and the latex content variation in asphalt-latex mixture](image-url)

![Figure 4](image-url)  [Figure 4. Relationship between the VIM and the latex content variation in asphalt-latex mixture](image-url)

3.4.5. Stability
Rahmawan [22] and Ramadan [23] researched latex as an added ingredient in asphalt mixtures. From these studies, it was concluded that the addition of latex could increase the stability value in the modified asphalt mixture. The stability value is an important parameter used to assess the resistance of an asphalt mixture to plastic discharge and show the ability of the asphalt mixture to withstand deformation due to traffic loads. The stability value in the HRS-WC mixture can be seen in Figure 5.
Figure 5 presents that the use of 1%, 2%, 3%, and 5% latex content in the HRS-WC mixture could increase the stability value of the HRS-WC mixture. In comparison, the use of latex percentages of 4%, 6%, 7%, and 8% in the HRS mixture could reduce the stability value because the penetration value also decreased. Thus, it affected the stability value of the mixture. It showed that the more latex content used, the lower the value of stability was due to the lack of asphalt percentages used in the mixture, resulting in many surfaces of the mixture not covered by asphalt and bond weakening between aggregates and asphalt. However, the results obtained had met the requirements of the specification. In other words, the resulting stability value indicated that the mixture was resistant to deformation.

3.4.6. Flow

Flow indicates sample deformation value due to the applied load until it achieves the collapse limit expressed in millimeters (mm) on a flowmeter watch. Flow value can be influenced by several factors, including asphalt content, aggregate surface shape, asphalt viscosity, the temperature at compaction, and aggregate gradation. The relationship between the percentage of latex with the flow for each mixture is shown in Figure 6. Figure 6 shows that the higher the latex content was, the lower the flow value became. This decrease occurred because the use of latex in asphalt mixtures increased the viscosity value of asphalt and the ability of asphalt to fill the cavities of the mixture, thereby the density of the mixture was high, and deformation was reduced. Furthermore, it can be concluded that the mixture with 1%, 2% and 3% of latex achieved the requirement by Bina Marga which more than 3.0mm of flow value, where it indicates the nature of the mixture became more flexible. Furthermore, according to the Bina Marga specification [6], the flow value required in the HRS-WC mixture was 3 mm. Hence, the use of latex meeting the requirements was at the percentage of 1%, 2%, and 3% latex.

Figure 5. Relationship between the Stability and the latex content variation in asphalt-latex mixture

Figure 6. Relationship between the Flow and the latex content variation in asphalt-latex mixture

3.4.7. Marshall Quotient (MQ)

Marshall Quotient is the quotient between stability and flow values and known as an indicator showing the approach of the rigidity value and the flexibility value of an HRS mixture. The higher the MQ value of a mixture is, the more rigid the mixture becomes. The lower the MQ value of a mixture is, the more flexible the mixture becomes. The relationship between the percentage of latex with Marshall Quotient for each mixture is presented in Figure 7. Figure 7 presents that all HRS-WC mixtures for various percentages of latex met Marshall Quotient requirements (≥ 250 kg/mm). Marshall Quotient values tended to get higher along with the greater use of latex content. This increase was due to a significant decrease in the flow value resulting from an increase in the use of latex content.
3.5. Marshall Comparison Results
In a nutshell, the optimum asphalt content (OAC) was 7%. In comparison, Rahmawan [23] and Ramadan [24] obtained optimum asphalt contents of 7.5% and 5%, respectively. The difference in optimum asphalt content results could be caused by several factors, including aggregate gradation, reference specifications, different supporting materials from both the fine and coarse aggregates used, fillers, and types of additive substances. The use of latex contents meeting the specifications in this study was 1% and 3%. The optimum latex content (OLC) was 1% because it showed the best performance. However, Rahmawan [22] and Ramadan [23] obtained optimum latex contents of 9% and 6%, respectively.

4. Conclusion
The test results carried out on the HRS-WC mixture using latex as a partial replacement for asphalt revealed that:
1) Marshall characteristic values with optimum results were achieved by a mixture of HRS with asphalt content of 7% and latex content of 1%.
2) The stability and MQ value increased at 1% and 3% latex contents.
3) The higher the latex content was, the higher the density and VFA values became.
4) The higher the latex content was, the lower flow, VIM, and VMA values became.
5) Latex could be used as a polymer material for modified asphalt because of its stability enhancing properties that prevent rutting.

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