The Effect of Technical Natural Rubber Mastication with Wet Process Mixing on the Characteristics of Asphalt-Rubber Blend

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Abstract. The modification of asphalt with natural rubber is believed to enhance asphalt Pen Grad 60/70. Natural rubber-type technical natural rubber with Standard Indonesian rubber (SIR) 20 was chosen as an asphalt additive. However, SIR 20 as an asphalt additive directly has the rubber distribution problem in asphalt, which tends to accumulate in certain parts of the asphalt mixture. Also, the use of SIR 20 requires a very long time in the mixing process to reach homogeneity. This study aims to determine the effect of adding technical natural rubber, Standard Indonesian Rubber (SIR) 20, both with and without mastication, on the characteristics of asphalt-rubber blends. The asphalt-rubber blend was developed by melting the SIR 20 at 200 °C before mixing it with asphalt under the melting point (170 °C). Evaluation of asphalt-rubber performance is measured using tests on penetration, softening point, and Marshall stability. While the asphalt rheological characteristics reviewed are complex modulus (G*), phase angle (δ), rutting factor (G* / Sin δ) before and after short-term aging. The results showed that the mastication process of SIR 20 could accelerate the asphalt-rubber mixture's homogenization process and produce asphalt with increased performance at high temperatures. The results show the addition of 10% MSIR has the best performance with a penetration value of 58.5 dmm, a softening point of 59.1 °C, Marshall stability of 1710 kg, and rutting factor of 5.46 kPa.

1. Introduction

High social mobility in developing countries such as Indonesia undeniably leads to traffic congestion because the growing number of vehicles outcompetes the road extension. Over time, traffic congestion imposes a considerable burden on the construction of paved roads, causing their surface to crack easily [1]. In addition to traffic jams, climate plays a significant part in road damage. Indonesia is a tropical country with two major seasons: dry and rainy seasons. The dry season with intense sunlight contributes to the high temperature on the road surface, which renders it prone to rutting [2], especially for roads made of asphalt pen grade 60/70 with a low softening point. During the rainy season, puddles and high humidity on paved roads cause the film layer wrapping the aggregate to get eroded and oxidized [3]. This, in turn, results in damages to the paved road layer, such as cracks and aggregate detachment.
One way to reduce the damage to the paved road layer is by reviewing the road construction and improve the quality of the asphalt through a modification process. Asphalt modification can be done by adding certain additives. For an additive to use for asphalt mixtures, it must produce high stability and softening points to reduce rutting on asphalt roads, as well as to increase flexibility on asphalt roads to minimize cracks and increase durability and the asphalt binding capacity to aggregates [4]. One potential additive to be used with asphalt is an elastomeric or rubber polymer. The natural rubber (NR) in Indonesia that potentially used is technical natural rubber with a Standard Indonesian Rubber 20 (SIR 20) specification. This is the main NR commercial product in Indonesia (over 90% usage). Indonesia ranks the second largest natural rubber producer in the world after Thailand, with rubber production reaching 3.774 million tons at the end of 2018.

Addition of 8% cup lump to 80/100 penetration asphalt. The results show that the addition of cup lump to asphalt significantly affects asphalt performance. The addition of an 8% cup lump can improve asphalt performance in preventing rutting by minimizing the rutting depth by up to 41%. This has a pretty good impact on increasing the ability of asphalt to withstand traffic loads and increasing the service life of asphalt after it is applied to roads [5].

The use of cup lump type natural rubber with a content of 4 – 12% as an asphalt mixture is proven to improve the rheology of conventional asphalt from the aspect of resistance to traffic loads and high temperatures. The results showed that as the cup lump content increased in asphalt, the penetration of cup lump modified asphalt decreased, and the softening point increased. High marshall stability provides better durability for asphalt to withstand traffic loads, increases asphalt rutting resistance, reduces asphalt deformation at high temperatures, improves fatigue resistance and anti-aging performance [6]. However, the water content, which is still quite high in the cup lump makes it difficult to mix in the asphalt due to the emergence of hot asphalt splashes.

This encourages the use of solid natural rubber as a mixture in asphalt. The addition of 3, 5, and 7% solid natural rubber with technical specifications of the Standard Indonesian Rubber (SIR) 20 type significantly affects the properties of the asphalt produced. A significant increase occurred at the softening point, which increased around 8 -10%, which indicated an increase in the susceptibility of asphalt to heat [7]. In addition, the use of solid natural rubber of the type of crepe rubber with a content of 8 - 12% showed the same good results as the use of SIR 20. Significant improvement was felt in terms of thermal and load resistance. However, the modified asphalt performance decreased after the addition of 12% solid natural rubber [8], [9].

The use of rubber in a solid form such as SIR 20 and crepe rubber is time-consuming in its mixing process; thus, a depolymerization process using mastication is required [10]. Mastication is a physical changing process of rubber from elastic to plastic. During the mastication, the polymer chain broke as a result of shear force by a roll mill. This process results in a decrease in the molecule weight and viscosity of the rubber. An efficient mastication process usually accomplished at temperatures below 60–70 °C and above 120–130 °C. The mastication process can accelerate by adding a plasticizer agent. The plasticizer agent used is pen grade 60/70 asphalt. It is the use of asphalt chosen as a plasticizer agent because of its more economical price. Compounds derived from hydrocarbon oil are suitable plasticizers for natural rubber. Asphalt itself is a hydrocarbon oil compound; thus, it is a suitable alternative to using a plasticizer for natural rubber [11].

Based on previous studies, modification of asphalt by using various types of rubber improves the asphalt quality increasing Marshall stability, softening point, resistance to rutting, and preventing premature aging of asphalt. This research will use technical natural rubber Standard Indonesian Rubber 20 (SIR 20). However, the addition of technical natural rubber SIR 20 in solid form becomes ineffective. It takes a long time in the mixing process to achieve a homogeneous asphalt-rubber mixture. Therefore, it is necessary to treat the mastication of SIR 20 to accelerate the rubber phase's homogeneity in asphalt. This study aims to investigate the effect of mastication on the characteristics of the asphalt-rubber mixture at the same rubber content. This study tests both masticated and non-masticated SIR 20, both with additives in the form of asphalt or masticated SIR 20 with asphalt (MSIRA) without additives or masticated SIR 20 (MSIR), using the wet process method.
2. Methodology

2.1. Material
The asphalt used in this study was asphalt penetration grade (Pen Grade) 60/70 produced by PT. Pertamina (Persero), Indonesia (the specifications from test are outlined in Table 1). The natural rubber used is a type of technical natural rubber with a Standard Indonesian Rubber 20 (SIR 20), produced by PT. Rickry, Riau, Indonesia, while the aggregates were taken from PT. Virajaya Riau Putra.

Table 1. Specification of Asphalt Pen Grade 60/70

| Parameters                          | Specification | Unit |
|-------------------------------------|---------------|------|
| Penetration at 25°C                 | 70.3          | Dmm  |
| Softening Point                     | 48            | °C   |
| Weight Loss on Heating by RTFOT     | 0.365         | %    |
| Penetration after TFOT              | 64.4          | Dmm  |
| Marshall Stability                  | 1179          | kg   |

2.2. Methods
SIR 20 initially diced to a size of 5×5×5 mm. Some SIR 20 masticated with 1% asphalt (MSIRA) addition and some without asphalt (MSIR). The mastication process used an open roll mill at 30 °C; the mastication process ran for 15 min until the MSIR and MSIRA sheets reached 1–2 mm thickness. Hereafter, the MSIR and MSIRA cut to 5×5 mm pieces. Non masticated SIR 20 heated to 200 °C to melting, then was mixed with asphalt with wet process method at 170 °C, with a variety of SIR 20 percentages 10% w/w. The mixing process employed a mixer at a stirring speed of 100 rpm for 30 min. Compounding samples also made of 10% MSIR and MSIRA using the same method. Table 2 listed all the prepared compound samples.

Table 2. Asphalt Treatment and Code Sample

| Asphalt Treatment | Asphalt Pen Grade 60/70 | Pen Grade 60/70 + 10% SIR 20 | Pen Grade 60/70 + 10% MSIR | Pen Grade 60/70 + 10% MSIRA |
|-------------------|-------------------------|-----------------------------|--------------------------|-----------------------------|
| Code Sample       | Asphalt Pen Grade 60/70 | 10SIR                       | 10MSIR                   | 10MSIRA                     |

Characterization of asphalt-rubber mixture samples includes penetration (ASTM D5), softening point (ASTM D36), rolling thin film oven test (RTFOT) (ASTM D6 / D6M), marshall stability (ASTM D6927), and storage stability (ASTM D7173-11). The Marshall stability testing employed aggregate composition 14% Coarse Aggregate, 30% Medium Aggregate, 45% Fine Aggregate, and 5% Filler Cement, with an optimum asphalt content of 6% for all asphalt-rubber samples. The complete results of asphalt modification (Penetration, Softening Point, RTFOT, and Marshall Stability). The Dynamic Shear Rheometer (DSR) test then performed to describe the viscoelastic behavior of asphalt-rubber. Testing using DSR performed for original asphalt samples, SIR 20, MSIR, and MSIRA before and after Short Term Aging.

3. Results and Discussion

3.1 Penetration
Adding 10% SIR 20 directly without mastication by the wet mixing process resulted in increased penetration of the asphalt-rubber mixture. The penetration value of 10SIR increases to 77.8 dmm or a 10% increase compared to the pen grade 60/70 asphalt (see Figure 1). This increased penetration
results from the SIR 20 having gone through the melting process. The melting process shortens the polymer chain in rubber and reduces the molecular weight of the polymer chain. The significant differences in molecular weight, density, chemical structure, and the ratio between SIR 20 particles and asphalt cause asphalt modification of SIR 20 to be unstable after mixing. As a result, some of the melted rubber will accumulate on the surface of the asphalt-rubber mixture. Some will settle so that the rubber phase is not evenly distributed in the mix [12]. Thereby changing the rubber-asphalt mixture’s rheology, characterized by a decrease in asphalt-rubber viscosity [15,16].

Figure 1. Penetration

The addition of melted rubber is different from the addition of solid SIR 20 added to the asphalt. Solid SIR 20 will cause asphalt-rubber penetration to decrease because SIR 20 absorbs light fractions in the asphalt. The absorption will cause the rubber to expand and form a viscous gel and phase rubber stable after mixing [15]. The size of the rubber particles mixed significantly affects the penetration of the asphalt-rubber maintains. The wider the SIR 20 particles’ surface area, the more asphalt light fractions are absorbed by rubber [16]. However, The use of SIR 20 melt contributes to increasing asphalt-rubber penetration. Increased asphalt concentration by SIR 20 melt mainly caused by a decrease in asphalt-rubber viscosity [14] and rubber melt accumulation on the asphalt-rubber surface [17].

Asphalt-rubber penetration decreases with the addition of 10% MSIR (10MSIR). The decrease in sample 10MSIR reaches 24.8% compared to that of 10SIR at the same content without mastication. The active side of the SIR 20 will bind to asphaltene, increasing the asphaltene molecular weight (see Figure 1) [18]. This process is responsible for the asphalt-rubber stiffness and reduces asphalt-rubber sensitivity to temperature. In addition to enhancing the asphalt-rubber resistance, the SIR 20 active side binding to asphalt increases the adhesion and cohesion bonds, which causes the asphalt-rubber to be more solid. This is characterized by a decrease in concentration and an increase in the asphalt softening point. Overall, mastication plays a significant role in decreasing the mixing time and increasing rubber distribution in asphalt [9,12].

The asphalt mixture with masticated crumb rubber with added 1% asphalt (10MSIRA) slightly increased penetration value than the 10MSIR mixture. The process of SIR 20 mastication by adding asphalt additives aims to accelerate the softening of rubber, prevent the occurrence of oxygen binding by free radical substances formed during the mastication process, and accelerate the mixing time. The addition of asphalt in the process of mastication may cause a pre-vulcanization reaction owing to the presence of sulfur, and other vulcanizing agents intrude the asphalt [19]. The formation of crosslinking (vulcanization) during the mastication process increases the rubber's melting point, causing the
distribution of the melted rubber to become uneven in the asphalt-rubber. The uneven distribution of MSIRA in the asphalt makes the asphalt mixture have problems with its storage stability. From Table 3, it can be seen that the storage stability of MSIRA has decreased as indicated by the increase in the difference in the upper and lower softening points of MSIRA.

3.2 Softening Point
The asphalt with the addition of SIR 20, MSIR, and MSIRA has a softening point increased compared with that of asphalt pen grade 60/70 (see Figure 2). The increase in the softening point was inversely proportional to the decrease in the asphalt-rubber penetration value. Asphalt pen grade 60/70 has a softening point of 48 °C. In contrast, that of asphalt with an addition of 10% SIR 20 (10SIR), the softening point increased significantly up to 52 °C.

The softening point that increased after the addition of SIR 20 caused by an increase in the proportion of semi-solids (resin) and solids (asphaltenes) to reduce the light fraction content in the asphalt [20]. The penetration value is inversely proportional to the softening point, which means a small penetration value results in a higher softening point. The addition of SIR 20 increased the molecular weight of the asphalt-rubber. The molecular density increases, and the higher the friction resistance on the test ball. The increased softening points may improve asphalt resistance to rutting and increase ductility, thermal stability, and aging time [21].

Figure 2. Softening Point

A higher amount of resin in asphalt due to the addition of SIR 20 increases the asphalt cohesion [22]. This increase is inversely proportional to the asphalt-rubber penetration value. Strong cohesion bonds will produce hard asphalt-rubber with a higher softening point. Apart from SIR 20 contents, another factor that affects the softening point is the mixing temperature. The softening point will increase with increasing mixing temperature until it reaches a temperature of 180 °C. It will decrease if the mixing temperature is raised. 180 °C is the optimal temperature for soft spots [23]. In contrast, any temperature beyond it will cause the polymer to degrade and lead to a decrease in the modified asphalt’s rheological properties.

Clearly explaining the asphalt-rubber interaction in improving asphalt quality is still difficult because of the complexity of SIR 20’s bond characteristics and asphalt’s chemical structure [24]. Despite its unclear characteristics, SIR 20, which some studies indicate to have a considerable molecular weight, will be released when mixed with asphalt. This will increase the stiffness of the tissue structure formed by asphalt-rubber molecules, leading to higher modulus (G*) and substantial asphalt-rubber stiffness [25].
The basic components of asphalt, such as saturate and aromatics will fill the cavities between the asphalt and polymers released during the mixing process. This instigates a growing interaction between the asphaltene molecules to increase and, thus, the asphalt-rubber viscosity will also increase [26]. Increasing asphalt-rubber viscosity can reduce asphalt-rubber penetration, leading to an increase in the asphalt-rubber softening point. Fig. 2 show a significant difference in the rise of the softening points for sample 10MSIR and 10MSIRA with the same softening point. The softening point 10MSIRA stood at 59.1 °C, rising 13.65% from that of sample 10SIR.

The even distribution of rubber caused the increase in soft points of 10MSIR and 10MSIRA samples. The mastication process will smoothen the particle size of the MSIR and MSIRA in the asphalt mixture. Besides, the mastication process also forms the SIR 20 active side that will bind to the asphaltene. The result of this binding is the formation of a stronger adhesion bond. The resulting asphalt-rubber also becomes harder [18]. The asphalt-rubber mixture with a high softening point has higher rutting resistance than decreasing asphalt-rubber sensitivity to changes in road surface temperatures.

3.3 Complex Modulus G*
Complex modulus (G*) is a parameter to measure the asphalt's total resistance to shear deformation. This discussion introduces elastic shear modulus and viscous shear modulus. The combination of elastic and viscous shear modulus reflects asphalt resistance to shear deformation affected by elastic and viscous proportions. Therefore, complex modulus (G*) is a factor considered in reviewing the performance of asphalt-rubber against high temperatures and aging. The complex modulus (G*) test for asphalt pen grade 60/70, 10SIR, 10MSIR, and 10MSIRA samples under test temperature conditions 58 and 64 °C before and after aging (see Figure 3A and 3B). The complex modulus of 10SIR, 10MSIR, and 10MSIRA samples has increased compared to asphalt pen grade 60/70. However, the complex modulus of 10MSIR and 10MSIRA samples decreased from 10SIR samples. The decrease in the 10MSIR and 10MSIRA samples' complex modulus is due to the higher proportion of viscous [9].

![Figure 3. A) Complex Modulus Before RTFOT and B) Complex Modulus After RTFOT](image-url)

In general, the value of complex modulus increases with aging and decreases with increasing temperature (see Fig. 3B). Increases and decreases in complex modulus caused by elastic and viscous proportions in asphalt [9]. The result of complex modulus (G*) has a good correlation with penetration. The higher the complex modulus of the asphalt indicates, the asphalt has low penetration. After aging of asphalt pen grade 60/70, 10SIR, 10MSIR, and 10MSIRA, the four samples' complex modulus increases significantly. The increase in complex modulus is attributable to an asphalt hardening after aging. On sure heating, the modulus complex of the four samples decreases because of
the proportion of viscous increases. These modulus complex results are consistent with the rutting and phase angle, where an increase in temperature changes the proportion of viscous to increase [9,12].

3.4 Phase angle (δ)
Phase angle (δ) shows strain versus stress data in asphalt viscoelasticity properties. In a general sense, the phase angle reflects the proportion between elasticity and viscous. Phase angle values can be valued at 0 (δ = 0°) if the material is fully elastic and valued at 90° (δ = 90°) if the material is completely viscous [28,29]. However, if the material is viscoelastic, the phase angle value is 0° - 90°. Phase angle of asphalt pen grade 60/70, 10SIR, 10MSIR, and 10MSIRA samples before and after aging (58 and 64 °C). The results show that the phase angle decreases with aging, and the phase angle increases with increasing aging temperature (see Figure 4A and 4B). The phase angle shows that the proportion of elasticity increases. This is directly proportional to the asphalt-rubber penetration, which decreases with aging and increases with increasing temperature. Thus, the phase angle can reflect asphalt-rubber performance against temperature changes [9].

10SIR sample has the lowest phase angle value compared to the 10MSIR and 10MSIRA samples (see Figure 4A). The lower phase angle value indicates that the asphalt-rubber mixture in the 10SIR sample has more elastic proportions than the 10MSIR and 10MSIRA samples. The 10SIR sample did not implement the mastication process for SIR 20 added to the asphalt. The mastication process accelerates the homogenization process and increases the distribution of SIR 20 in the asphalt mixture[18]. The combination of the mastication process and the melting of SIR 20 resulting asphalt properties which have a higher proportion of viscous compared to the SIR 20 without mastication (Sample 10SIR).

Whereas in figure 4B, the phase angle decreases with aging and increases with increasing temperature. After aging, the phase angle value has decreased by losing most of the light fractions in asphalt during RTFOT [9]. The loss of light fraction in asphalt decreases the sensitivity of asphalt to temperature. It increases the proportion of elasticity of asphalt. Consequently, asphalt after aging is getting harder, which is illustrated by decreased penetration after RTFOT. Comparing the phase angle of the asphalt pen grade 60/70, 10SIR, 10MSIR, and 10MSIRA samples at 58 and 64 °C, the phase angle increases with increasing temperature. In the higher temperature, the asphalt properties change from initially close to elastic to viscous [9].

3.5 Rutting Factor (G* / Sinδ)
The combination of modulus complex (G*) and phase angle (δ) is used to describe the performance of asphalt against rutting. The rutting factor (G* / Sin δ) at test temperatures of 58 and 64 °C is related to
asphalt performance on rutting, causing permanent deformation. At high temperatures, the greater the value \( \frac{G^*}{\sin \delta} \) indicates, the better performance of asphalt in holding rutting (anti-rutting) [9]. Fig. 5A shows the value \( \frac{G^*}{\sin \delta} \) of asphalt pen grade 60/70, 10SIR, 10MSIR, and 10MSIRA at a certain temperature before aging.

![Figure 5A and 5B](image)

**Figure 5.** A) Factor Rutting Before RTFOT and B) Factor Rutting After RTFOT

Increase \( \frac{G^*}{\sin \delta} \) after the addition of SIR 20 and decreases with increasing test temperature (see Figure 5A). The increase in value \( \frac{G^*}{\sin \delta} \) after the addition of SIR 20 indicates that the asphalt became stronger after SIR 20 with the highest increase \( \frac{G^*}{\sin \delta} \) reaching 8.52 kPa. However, \( \frac{G^*}{\sin \delta} \) decreased by 35 - 40% in 10MSIR and 10MSIRA samples compared to 10SIR samples. According to Figure 5A, the 10SIR sample has a higher rutting resistance than the 10MSIR and 10MSIRA samples. That is because the proportion of elasticity in the 10SIR sample is higher than the 10MSIR and 10MSIRA samples so that the elastic shear modulus of the 10SIR sample gets bigger.

Figure 5B shows that \( \frac{G^*}{\sin \delta} \) increases with aging. This indicates that asphalt is getting harder after aging marked by a decrease in asphalt-rubber penetration. However, when the temperature increased from 58 to 64 °C there was a decrease \( \frac{G^*}{\sin \delta} \) in the sample before and after aging. Increasing the test temperature changes the viscoelastic property of the asphalt-rubber sample [9]. Decreased value \( \frac{G^*}{\sin \delta} \) affects resistance to deformation and deformation recovery weakens [27].

Comparison results from 10SIR, 10MSIR, and 10MSIRA samples show that the asphalt performance after the addition of rubber is better than asphalt pen grade 60/70. In particular, the 10MSIR sample has the best rutting resistance performance at high temperatures and has better thermal stability than 10SIR and 10MSIRA. 10MSIR became the best sample due to an increase \( \frac{G^*}{\sin \delta} \) after RTFOT compared to the 10SIR sample, which decreased. A decrease in value \( \frac{G^*}{\sin \delta} \) after RTFOT is not expected to occur because it indicates that the asphalt-rubber mixture does not have good thermal stability.

### 3.6 Marshall Stability

The stability of the asphalt-rubber mixture with aggregate is essential for the road to hold traffic loads without suffering deformation [20]. Besides, the asphalt-rubber mixture's stability must have rutting resistance and better performance in both high and low temperatures. Adding rubber into asphalt pen grade 60/70 strengthens the interaction between the asphalt-rubber and the aggregate, increases resistance to moisture, and leads to higher durability and better noise attenuation rates [9,29,30]. The stability of 10SIR marshall increases up to 1393 kg or an increase of 18% compared to asphalt pen grade 60/70. The results of the asphalt mixture stability test are shown in Figure 6.
This study used optimum asphalt-rubber levels (6%) of the total mixture applied to all samples. The underlying principle is that Siswanto et al. (2017), a higher asphalt-rubber level in the aggregate mix, will render the asphalt-rubber mixture more susceptible to rutting and deformation characterized by a decrease in the value of the asphalt-rubber mixture stability [31]. The highest stability of the asphalt-rubber mixture in this study was obtained by adding 10% MSIR (10MSIR) with marshall stability highest 1710 kg. The increased durability after the addition of SIR 20, MSIR, and MSIRA owes to the change in the rheology and increase in the cohesion and adhesion of asphalt caused by the added rubber [9,23,32]. In addition, adding SIR 20, MSIR and MSIRA to the asphalt will cause the asphalt-aggregate mixture to become stiffer and harder.

10SIR, 10MSIR, and 10MSIRA have the same rubber content but result in a significant difference in marshall stability. This significant difference in stability was influenced by the penetration value and storage stability of the three samples. The difference in the penetration value of 10SIR, 10MSIR, and 10MSIRA shifts the optimum asphalt content used in the manufacture of Marshall specimens. Failing to meet an optimum level of asphalt will cause the asphalt-rubber mixture to be more prone to permanent deformation and rutting permanently, contributing to the low stability value of the asphalt-rubber mixture [33,34].

At the 10SIR mixture, the asphalt-rubber mixture's stability value increases, which opens a possibility for the quality of asphalt-rubber to be improved. The Marshall stability test shown in Figure 6 demonstrates that the 10MSIR mixture's stability reached 1710 kg, while that of 10MSIRA mixture stood only at 1404 kg. The 10MSIR mixture, therefore, is likely to increase the potential of asphalt-rubber in terms of stability because the rubber has a low penetration, which indicates that the adhesion and cohesion within the asphalt-rubber are better than what is found between 10SIR [18,22,32]. However, note that mixing asphalt with 10% MSIRA (10MSIRA) does not significantly change the value of stability.

This study shows that the 10MSIR mixture is the most optimum combination for road construction because the value of void filled aggregate (VFA) in the mix reached 87.2% (VFA limits is 65%). The large VFA value indicates the asphalt-rubber mixture ability to fill cavities between aggregate grains due to stronger bonding between aggregates and the asphalt-rubber cohesion and adhesion, leading to a high value of stability. This means that the VFA value is inversely proportional to void in the mixture (VIM) and void in mineral aggregate (VMA) values. The 10MSIR mixture has VIM and VMA values of 1.97 and 15.37%, respectively, good indicators of asphalt-rubber tightness. The impermeable asphalt-rubber mixture will inhibit the oxidation of asphalt-rubber and thus delay the
asphalt-rubber aging. Besides, the flow value produced is only 4.7 mm, which suggests that the asphalt-rubber is rigid and resistant to rutting.

A few factors influence the stability of the asphalt-rubber mixture, which makes a significant difference between this study and others' findings. These are the optimum asphalt-rubber content in the mixture, gradation and composition of the aggregate in the mixture, penetration of the asphalt-rubber, mixture viscosity, and mixing temperature and compactness [33,34]. Better asphalt-rubber stability provides better asphalt-rubber resistance to traffic loads, increased rutting, reduced deformation at high temperatures, reduced resistance to fatigue, and anti-aging due to SIR's addition 20 [9,35].

4. Conclusion
This paper provides several conclusions regarding the addition of melt crumb rubber SIR 20 that could increase the physical property of rubberized asphalt blend. A direct addition of SIR 20 melt increases asphalt penetration value but has no significant effect on the asphalt performance either in low or medium temperatures; hence, the risk of rutting could still occur, which is marked by the increase in the asphalt softening point that only reached 52 °C. The mastication process of CR SIR 20 offers a significant influence on the reduction of penetration, upsurge of thermal stability, and better ability to withstand the weight compared to a direct addition of CR SIR 20. A significant increase appears on the MSIR sample with a softening point reaching 59.1 °C and a Marshall stability reaching 1710 kg. The mastication process in SIR 20 affords an advantage to a shorter mixing time, a low melt temperature, and better physical characteristics of the asphalt than without mastication. The use of MSIR and MSIRA basically impacts positively on the sample of the asphalt, and MSIR is better at bearing weight compared with MSIRA. Anti-rutting performance of the 3 types of asphalt-rubber mixture is superior to asphalt PG 60/70. The 10MSIR sample had the best anti-rutting performance with a rutting factor value (G* / Sin δ) of 5.46 kPa before RTFOT and 6.75 after RTFOT, followed by 10SIR and 10MSIRA.

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