Effects of cup lump natural rubber as an additive on the characteristics of asphalt-rubber products

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Abstract. Asphalt penetration 60/70, which is widely used for road construction in Indonesia, is the cause of road deterioration due to high traffic loads and climate changes. Therefore, the addition of polymer additives can be one of the solutions to improve the quality and service period of asphalt. The aim of this research is to study the effect of cup lump natural rubber content on the characteristics of asphalt-rubber products. The mixture of asphalt-rubber is made by melt the cup lump at 130°C, then mixed it with asphalt at 170°C. The result showed that the addition of cup lump would decreased the penetration and weight loss properties, but increased the properties such as softening point, ductility, and Marshall stability of asphalt-rubber products. The optimal addition of cup lump was at 12% with penetration 52,4 dmm, softening point 63,5°C, ductility 142 cm, weight loss 0,068%, and Marshall stability 1904,36 kg.

1. Introduction
The land transport plays an important role in economic development of a city or region. In Indonesia, the growth rate of motor vehicles increased annually about 7,4%. However, if the growth was not accompanied by the length of the road, it will cause a traffic congestion. A traffic congestion for a long period gives big load into a road construction, it will cause cracks or rutting. In addition, other factors of road deterioration in Indonesia are climate change, water, humidity, and quality of asphalt that mostly bad [1]. In 2017, it was reported that length of paved roads reached 321.093 km where 16,72% damaged and 17,36% heavily damaged. In fact, refinement will increase the maintenance cost of paved roads annually [2]. Therefore, preventive action is by re-analyze road construction and improve quality of asphalt through modification. Modification can be done by addition of an additive into asphalt. It must be able to produce high stability and softening points, increase flexibility, increase durability, and increase binding capacity of asphalt to aggregate.

One of the additive is Cup Lump (CL) natural rubber. In fact, Indonesia is second ranked as rubber producers country in the world behind Thailand, as its production reached 3,774 million tons at the end of 2018 [3]. Rubber farmers are the main contributor (about 85%) of Indonesia's natural rubber production, which is a CL type. About 85% of Indonesia’s natural rubber were exported to several countries such as United States, China, Japan, and etc [4]. The high export rate caused rubber price to
be unstable. According to data January 2017 till January 2019, the rubber prices were decreased to 48.1% [5]. Thus, to maintain stability of rubber prices is by increasing consumption at the domestic level.

Some researches have been done with rubber as additive for the asphalt. CR from wasted-tires, Blok Skim Rubber (BSR) and Crumb Rubber Standard Indonesian Rubber 20 (SIR 20), if they were used directly as additives for asphalt, it will require very long mixing time and higher temperature. The addition of rubber in solid form is less desirable because the molecules chain of the rubber is very long. Therefore the rubber processing before it was mixed is very important. Wen [8] added latex with Dry Rubber Content (DRC) > 60% into conventional asphalt. The problem faced in using latex as additive is the formation of hot asphalt splashes due to the high water content in latex. Besides using rubber and latex as an asphalt additive, Cup Lump (CL) natural rubber can also be used as an asphalt additive. The addition of CL changes the asphalt rheology by increasing softening point but decreases penetration and ductility [9]. The use of cup lumps is more desirable than latex due to the short mixing time and lower mixing temperature.

In general, these studies show that modification of asphalt using various types of natural rubber have a great impact on improving the quality of asphalt. The improvement specifically occur on durability, resistance to temperature, resistance to rutting, and prevention to short aging. This study was conducted to study the effect of cup lump natural rubber as an additive on the characteristics of Marshall specifically roughness, stiffness, temperature sensitivity, and durability for asphalt to resist traffic load.

2. Materials and Methods

2.1 Materials

The asphalt used in this research was asphalt Penetration 60/70 that obtained from PT. Pertamina (Persero) Indonesia, with specification as shown within Table 1. The type of natural rubber used in this research was Cup Lump obtained from locals’ rubber plantation in Kampar, Riau Province, Indonesia. While the aggregate was processed aggregates from PT. Virajaya Riau Putra, Riau Province, Indonesia. Its specification shown within Table 2.

| Properties                  | Test Standard | Test Result |
|-----------------------------|---------------|-------------|
| Penetration at 25°C (dmm)   | ASTM D5       | 70,2        |
| Softening point (°C)        | ASTM D36      | 48          |
| Weight Loss by TFOT (%)     | ASTM D6       | 0,365       |
| Penetration After TFOT (dmm)| ASTM D5       | 64,7        |
| Ductility (cm)              | ASTM D113     | 110         |
| Marshall Stability (kg)     | ASTM D6927    | 1179,25     |

Table 2. Composition of Aggregate on Marshall Stability Test

| Aggregate   | Composition (%) |
|-------------|-----------------|
| Coarse      | 14              |
| Medium      | 30              |
| Fine        | 45              |
| Filler Cement | 5              |

2.2 Preparation of Modified Asphalt Samples

Cup Lump (CL) was first cut into small pieces into a cube size 1 cm x 1 cm x 1 cm. Then CL was melted at 130°C for 15 minutes. The CL was mixed together with asphalt under melted condition at 170°C, where CL content were varied at 4%, 6%, 8%, 10%, and 12% w/w. The materials were mixed by mixer with 100 rpm of speed for 30 minutes.
2.3 Characterization of Modified Asphalt Samples

Characterization of asphalt-rubber samples were consisted of Penetration Test (ASTM D5), Softening Point (ASTM D36), Weight Loss (ASTM D6 / D6M), Penetration After TFOT (ASTM D5), Ductility (ASTM D113), and Marshall Stability (ASTM D6927). Marshall Stability test were carried out using composition of aggregate as shown in Table 2 with optimum asphalt content 6% for all samples. Then, sample that gave the best Marshall test result were followed by Void Filled Aggregate (VFA) Test, Void In Mixture (VIM) Test, and Void Mineral Aggregate (VMA) Test.

3. Results and Discussion

3.1 Effect of Compo Ratio on Penetration of Modified Asphalt

The addition of CL as an additive into conventional asphalt produces Cup Lump Modified Asphalt (CMA) with different rheological properties compared to conventional asphalt, which is penetration properties. The result shows that the penetration decreased 16,38% with the penetration value 58,7 mm on additions of 4% CL. An excessive of CL ratio caused the penetration value to continue decrease till it reached 52,4 dmm on additions of 12% CL or decreased 25,35% of conventional asphalt. Figure 1 shows the result of CMA penetration test.

![Figure 1. Effect of CL Ratio on Penetration of Modified Asphalt](image)

The penetration decreased as the increasing of CL content, it is due to the increasing of asphaltene content and decreasing of maltene content. The ratio of asphaltene and maltene have a great impact on rheology of asphalt. The increase of asphaltene content hardened the bitumen, increased the softening point, and lower the penetration value which indicated higher viscosity [10]. The CL used in this study has a Dry Rubber Content (DRC) ≥ 55%. CL molecules are made up of straight polyisoprene hydrocarbon chains. Its physical appearance is like a flocculant sponge. Heating at temperatures below 100ºC causes CL which is elastic turn to be stiff and slightly hard, whereas when heated above 100ºC, CL will become flexible, soft, and transparent due to depolymerization [11].

The modifying of asphalt with CL used a mixing temperature of 170ºC, a high temperature causes the water bound in the asphalt to be released in the form of water vapor. The release of large water vapor causes cavities between polymer molecules caused by CL structures such as sponges [11]. The basic components of asphalt such as saturate and aromatics will fill the cavity that was previously filled with water that has been released during the mixing process. This causes the asphaltene component to increase which results in strong interactions between the asphaltene molecules.

Rubber that expands for a long time and high temperatures causes the rubber to depolymerize [12]. Depolymerized CL will evenly distributed in the asphalt so that the absorption of light asphalt fractions increases. The increased asphaltene and resin ratio due to the light fraction absorbed by CL has a considerable impact on the performance of the resin. Resin in asphalt is polar and by increasing resin content have an impact on increasing adhesion, ductility, flexibility and plasticity [13]. Increasing the
asphalt adhesion is related to the increase in adhesion and cohesion properties of asphalt. Increasing asphalt adhesion causes the asphalt to become harder with indications of low asphalt penetration [6].

3.2 Effect of Compo Ratio on Softening Point of Modified Asphalt
The result shows that penetration of CMA decreased as the increasing of CL content, simultaneously increased the softening point of modified asphalt. The softening point increased as the increasing of asphaltene content and decreasing of maitene content linearly [13]. Modified asphalt with the addition of CL gave resistance to higher temperature. The addition of 12% CL on CMA increased its softening point value by 32.3% from conventional asphalt, with softening point 63.5ºC. The effect of CL addition on asphalt can be seen in Figure 2.

![Figure 2. Effect of CL Ratio on Softening Point of Modified Asphalt](image)

The increased of softening point directly proportional to the increased of asphalt viscosity and cohesion [10,11]. It is indicate that an increased of asphalt stiffness as an effect of increased molecular weight. The increase of molecular weight creates more obstacles on the asphalt when softening point test is carried out [14]. Besides CL content, other factor that affects the softening point is mixing temperature. The softening point will be optimal at mixing on 180ºC, but the rubber will be degraded if it exceeds the temperature [15]. At high mixing temperature, depolymerization process will take place quickly and CL will evenly distributed in the asphalt [6,8]. The addition of 4% CL has a significant effect on the increase of softening point, with an increase 18.95% and softening point 57.1ºC. The addition of small amount of CL in the asphalt has a great impact on rheology against stiffness and thermal resistance.

3.3 Effect of Compo Ratio on Ductility of Modified Asphalt
The result shows that a slight addition of CL has a great impact on penetration and softening point value. One of the reasons of penetration decreased and increased on softening point because of the high cohesion bond of the asphalt. The increased of cohesion bond of the asphalt is characterized by an increase in ductility. The effect of CL addition on ductility can be seen in Figure 3.
Fig. 3 shows the results of ductility values, it shows that the addition of 4% CL increased ductility 6.36% from conventional asphalt. The addition of 12% CL gave highest ductility to 142 cm or 29% from conventional asphalt. Ductility was strongly influenced by cohesion bond of asphalt [10], the fraction in asphalt that has great impact on cohesion is resin. Ductility of asphalt increased as the increasing of resin content, but will decrease if there is an increase of asphaltenes and oil content. A high ductility indicated that the asphalt were elastic, it is related to the smaller the size of rubber particles in a mixture that can increase elasticity of rubber [11]. On this research the ductility were increased, it is due to a high mixing temperature so that CL were evenly distributed in the asphalt. Gagle [16] stated that the addition of Styrene and Butadiene could improve ductility at high mixing temperature. On the other hand, natural rubber particles that evenly distributed at high temperature can reduced the increased of asphaltenes content, simultaneously improved cohesion and adhesion properties of asphalt without reduce ductility. The increased of ductility made asphalt more flexible and improve the susceptibility to cracks on low temperature. The addition of rubber also improved the tensile strength, toughness, and thermal resistance.

3.4 Effect of Compo Ratio on Weight Loss and Penetration of Modified Asphalt After TFOT

Weight loss referred referred in this test is the difference of weight sample before and after Thin Film Oven Test (TFOT). Weight loss occur because volatilization of aromatic components such as benzene and xylene [11]. The amount of weight loss indicated sensitivity of asphalt to temperature. TFOT testing aims to determine effect of volatile compounds on aging and sensitivity of asphalt to high temperature. The maximum weight loss of asphalt permitted were only 1% of asphalt weight [9].

Fig. 4 (a) shows the addition of CL reduced the weight loss of asphalt component. Weight loss was reduced from 63% to 81.36% of conventional asphalt at 4% - 12% of CL content. The CL was acted as membrane for light fractions in asphalt [9]. Aromatic and saturated components were decreased as the length of mixing time due to absorption of rubber, however, asphaltenes component and resin were unchanged [11]. The greater the loss of weight, the more hardening or aging is found. Weight loss (volatilization) and oxidation are two main causes of the aging of asphalt. Short-term aging was caused by the loss of volatile and oxidizing components during the construction period. While the long-term aging was caused by traffic loads, temperature changes, sunlight, oxidation, etc. [17]. The aging of asphalt caused asphalt harden, so the asphalt was easier to cracked. The weight loss of asphalt caused decrease of penetration value and increase of softening point.
Figure 4. Effect of Compo Ratio on (a) Weight Loss and (b) Penetration of Modified Asphalt After TFOT

Figure 4 (b) shows the decreased of penetration value about 0,8% to 2,2% after TFOT, the lowest of penetration value were 51,6 dmm at the addition of 12% CL. The weight loss after TFOT reduced the penetration due to the increased of asphaltene and resin content. The increased of asphaltene ratio caused asphalt to become harder and has a low penetration value. Meanwhile low penetration asphalt tends to had weight loss and penetration after TFOT the lowest [11]. It is suitable for use in hot climates because low penetration asphalt tends to had a higher softening point [18]. Asphalt with low penetration tends to have rutting resistance and fatigue during service period [19].

3.5 Effect of Compo Ratio on Marshall Stability of Modified Asphalt

Application of modified asphalt must possess ability to withstand traffic loads without permanent deformation [18]. In addition, the stability of asphalt mixture must have rutting resistance and better performance on high and low temperatures. The advantages of adding rubber into asphalt in its application are better driving quality, moisture resistant, higher durability, reduced sensitivity to temperature, and low noise levels. Figure 5 shows the highest stability Marshall was 1904,36 kg or up to 61,5% at the addition of 12% CL. The addition of 4% CL did not have significant effect on the increased of stability Marshall. The result shows that optimal CL addition is between 6% - 12% with an increase in stability 20.6% - 61.5%. This study used optimum asphalt content 6% of the total mixed
weight applied to all samples. With asphalt content that are not optimum in the aggregate mixture, the greater possibility of rutting and deformation will be [20]. The addition of CL changed rheology of asphalt in binding the aggregate to be stronger due to increased cohesion and adhesion [11].

The addition of 12% CL is the most optimum to be applied as road construction because it has high stability and softening point. It has Void Filled Aggregate (VFA) up to 51.2%. A small VFA value indicates the asphalt was unable to fill the void between aggregate grains. However, even though the resulted VFA value is small, the cohesion and adhesion bond between asphalt and aggregate remain strong so that they have a high stability value. The VFA value is inversely proportional to the value of Void In Mixture (VIM) and the value of Void in Mineral Aggregate (VMA). The asphalt mixture with CMA had VIM value of 11.9% and VMA value of 24.37% which indicated poor asphalt tightness. The asphalt mixture that was not impermeable will easily oxidized which leads to short aging. The value of VIM and VMA indicated that the asphalt is pivot and susceptible to erosion of the asphalt film covering the aggregate by water, as well as the risk of deformation due to increasing the traffic loads.

![Marshall Stability vs Rubber Content](chart.png)

**Figure 5.** Effect of Compo Ratio on Marshall Stability of Modified Asphalt

The stability of the asphalt-rubber mixture can be influenced by several factors that make a significant difference to the results of other studies. These are several factors that have a great impact to the stability of the asphalt mixture are the optimum asphalt content in the mixture, gradation, and composition of aggregate in the mixture, the penetration of asphalt – rubber that used, mixed viscosity, mixing temperature, and compaction. The increased of Marshall stability gave better durability for asphalt to resist traffic load, increase the rutting resistance of asphalt, reduce deformation of asphalt at high temperature, increase fatigue resistance and anti aging performance.

4. Conclusions
Cup Lump (CL) natural rubber, which is used as an asphalt additive, is proven to be able to improve rheology of conventional asphalt from the aspect of resistance to traffic loads and high temperature. The result showed that along with the increase of CL content in asphalt, the penetration of CMA would decrease and the softening point would increase. The optimal addition of CL was at 12% with penetration 52.4 dmm, softening point 63.5°C, ductility 142 cm, weight loss 0.068%, and Marshall stability 1904.36 kg. Weight loss 0.068% indicated the asphalt was more resistant to short aging during service period. The high Marshall stability gave better durability for asphalt to resist traffic load, increase the rutting resistance of asphalt, reduce deformation of asphalt at high temperature, increase fatigue resistance and anti aging performance.
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