Temperature Effect on the Deformation of the Recycled Hot-Mix Asphalt Concrete with Nano Crumb Rubber as an Added Material with Wheel Tracking Machine

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Abstract. The use of materials for the construction of roads can be done by recycling asphalt concrete mixtures that have reached fatigue or aging conditions. The results from stripping the asphalt concrete layer on the surface layer can be reused after processing by recycling the material. The recycling process is often intended to preserve the environment from natural damage due to the processing of material for asphalt concrete mix. To improve the performance of the recycled mixture, additives have been widely used and the use of building materials as additives can also be obtained from building material waste. One of the waste that continues to increase is the waste of vehicle tires. In this research used tire waste that has been mashed up to Nano size. The use of finer used tire sizes is intended to facilitate the process of mixing with asphalt. Recycling performance of hot mix asphalt concrete on deformation performance has been used rutting test using Wheel Tracking Machine at a temperature of 27°C, 40°C and 60°C. The test results showed a decrease in the rate of deformation in the asphalt concrete recycle mixture using Nano crumb rubber added material.

1. Introduction

The use of materials for buildings including road construction has been oriented towards environmental sustainability efforts. Rock material mining permits are increasingly restricted so that material recycling technology is being developed. Pavement material recycling technology that can produce new pavement material as a result of the saving of material, money, and energy. Materials of old pavement can still be utilized even though this pavements layer has reached at the end of its service life. The utilization of asphalt mixture that has been used, over the years, mixed with new aggregates and asphalt has been able to produce new asphalt mixture. This way has proved economical and effective in protecting the environment [1]. Increased number of road construction material needs as a consequence of the increase of the number of vehicles and the load axis of truck vehicles. Road construction should be able to serve traffic during the service period.

Long-term sustainability programs with technological advancements have allowed longer material life so that they can reduce costs over the service life. Also, the use of local materials, low-energy technology, recycling processes and waste material reduction programs as part of this program [2]. Road surface layers are a part of road construction that receives direct repetitive traffic loads so that structural damage occurs faster than other layers of the road structure. Restoration of the performance of the surface layer can be done by overlaying the old layer or by stripping the surface layer and replacing it with a new asphalt mixture. Recycle asphalt pavement (RAP) is a technique for mixing old asphalt
binding and aggregate by adding new material produced by hot mix-asphalt (HMA). This method is known as the most common recycled material in flexible pavement.

The material additive is needed in high RAP content, due to crack performance, increased stiffness of asphalt mixture and difficulty in the compaction process [3]. Damage to the asphalt mixture can occur due to the aging process of asphalt in the mixture during the service period or changes in grain size due to repeated loading. The recycling process is the recovery of asphalt content in the mixture or the restoration of the aggregate composition. Asphalt pavement recycling has the advantage of saving raw materials. Asphalt pavement recycling has the advantage of saving raw materials. This is part of one of the sustainable strategies that have been developed and used in the road pavement industry on several years. The use of RAP can reduce the need for transportation of virgin asphalt binder, especially when it must be transported from foreign countries over long distances [4].

One technique to reduce environmental pollution, waste tire materials and waste engine oil has been widely used in asphalt mixtures for road pavement construction. The use of crumb rubber from tire waste has been widely used in asphalt mixes as an alternative to making modified asphalt, with the aim to improve the performance of the asphalt mixture and prevent plastic deformation. The addition of crumb rubber modifiers (CRM) to the asphalt mixture has increased the viscosity and elasticity of asphalt and at the same time, increased their resistance to the aging process [5]. Utilization of CRM in aggregate asphalt mixtures using certain techniques so that Crumb Rubber (CR) can be homogeneously mixed in asphalt mixture as a modified asphalt mixture. The use of CR on road pavement has been tried in many ways, especially when CR is mixed directly into asphalt (wet process) or, by mixing with aggregate during aggregate heating. This process is carried out before the addition of asphalt in the hot-mix asphalt (dry process) [6]. The properties of CR in asphalt mixtures at various temperatures are uncertain, this is due to the various effects of CR interactions with asphalt binders, largely influenced by the chemical properties of asphalt binders and the CR content in asphalt mixtures, particle size, texture, temperature and interaction time [7].

In this study, the RAP processing uses waste engine oil (WEO) to soften aged asphalt and add CR that has been processed to Nano size as a modified asphalt mixture. Virgin asphalt has been used in the Asphalt Concrete Wearing Coarse (ACWC) specification for hot-mix asphalt as a reference for evaluating the performance of modified asphalt mixtures.

2. Materials and Methods

2.1. Aggregate and Binders

In this study, recycled asphalt pavement was produced by 60/70 pen asphalt binder and a nominal maximum aggregate size of 19 mm. The RAP obtained from the Jakarta Outer Ring Road toll road has been extracted in the laboratory to determine the asphalt and aggregate characteristics. RAP asphalt binder is extracted through trichloroethylene solvent and obtained using a centrifuge extractor. The extraction results produced data from the studied RAP showed that the asphalt content was 5.8%, and had a very low penetration value of less than 10. These data were obtained from all three samples that had been tested. From the results of this test can be calculated the need for new asphalt and waste oil engine content into the RAP. Tests to control the performance of this recycled asphalt mixture have used the Asphalt Concrete Wearing Coarse (ACWC) specifications with the grain structure as shown in figure 1. The arrangement of the RAP aggregate is formed from the ACWC specification by adding new aggregates.
Pen 60/70 virgin asphalt was chosen as an additional binder for all specimens containing RAP. The binder specifications that have been used in this study are presented in table 1. Furthermore, to improve the resistance of the asphalt mixture to cracking, the binding material is modified with CR.

**Table 1. Specification of binders.**

| No. | Type of Testing | Method | Indonesian Asphalt 60/70 | Virgin Asphalt | Aged Asphalt |
|-----|-----------------|--------|--------------------------|----------------|--------------|
| 1   | Penetration (25°C, 5 s, 100 g)/0.1 mm | SNI 2432:2011 | 67.75 | 62.5 | 8 |
| 2   | Loss on heating (TFOT) | SNI 06-2440-1991 | 0.034 | 0.108 | 0.35 |
| 3   | Penetration after TFOT | SNI 06-2456-1991 | 58.5 | 61 | 5.8 |
| 4   | Softening Point (° C) | SNI 2432:2012 | 51.5 | 45 | 65.3 |
| 5   | Flash Point (° C) | SNI 2433:2011 | 263 | 306 | 322.6 |
| 6   | Solubility in Trichloroethylene (%) | AASHTO T44-03 | 99 | 99 | 89.8 |
| 7   | Ductility (cm) | SNI 2432:2012 | >100 | 107 | 12.3 |
| 8   | Specific Gravity | SNI 03-6893-2002 | - | 1.048 | 1.07 |

2.2. *Waste Engine Oil*

Based on physical testing of RAP, the results show that RAP tends to have a rigid nature. This is evident from the very low penetration and ductility values. To reduce these rigid properties, waste engine oil (WEO) is needed as a softener material for RAP. The mixture of RAP and WEO in the ratio of 11:4 gives the penetration results according to specifications, the value is in the range of 60 to 70. The percentage of volatile components in WEO tolerate under high temperatures during the production process. In other words, waste oil is highly qualified for applications in the asphalt mixing process because of its stability at temperatures above 220°C [3, 8].

2.3. *Crumb Rubber*

In this research, used tire material as waste has been crushed into fibre particles through 3 stages. The first stage used tires are destroyed by the ambient process at room temperature into small particles, in this initial process the particles still have metal and fabric so they must be separated. This separation process is carried out in the second process, and in this process also carried out particle size separation,
where the size of large particles will be reprocessed. The third process is the separation of metals with magnets and the separation of fabric particles with air. The three stages of the Crumb Rubber milling process are carried out at PT Daurindo Indonesia, Bogor Indonesia. The process of mixing CR with asphalt with a method is very difficult to get a modified asphalt mixture where CR can spread homogeneously in asphalt. The change in shape from CR in the form of fibres to finer-sized granules is expected to complete the mixing process more evenly. This advanced grinding process has been carried out in laboratories that are still on a small scale.

2.4. Recycle Asphalt Pavement
The use of recycled materials for road pavement has been widely carried out in several countries. This is an effort to save the use of new material by making maximum use of the strength of the remaining old material by adding new material. RAP is common recycled materials that are used in asphalt mixtures due to the ability of these asphaltic materials to partially substitute the need for virgin aggregates and asphalt binder. For an asphalt concrete (AC) mix, the percentage of virgin asphalt binder that is substituted by recycled asphalt binder from RAP is known as the asphalt binder replacement (ABR) ratio [9].

In this study the asphalt content of RAP material was 5.8% of the total mixture using the ACWC specification, as a comparison a new asphalt mixture was made with an optimum asphalt content of 6% of the total weight of the asphalt mixture. The RAP mixture from the cutting of the road surface has been mixed with WEO of 36.67% of the aging asphalt content or 2.18% of the total weight of the RAP. The mixture of RAP and WEO has been stored for 24 hours in a closed container. New aggregate material has been added to meet the ACWC middle aggregate specifications as shown in figure 1. RAP changes colour darker and wetter than the previous RAP (figure 2). The next step is the RAP mixing process by heating the RAP + WEO mixture at 160°C, and then adding NCR before adding virgin asphalt.

![Figure 2](image_url)

Figure 2. Before (a) and after (b) the WEO addition.

2.5. Wheel Tracking Machine
As a result of repetitive vehicle wheel paths on the road surface can cause a decrease in road surface, asphalt mixture is not able to accept the traffic load. On the road lane often dominated by heavy vehicles, the shape of the wheel path deformation will be faster.

The wheel tracking machine (WTM) test produces data to determine the resistance of asphalt mixes due to wheel path deformation, and this test also simulates the traffic loading or vehicle wheel load on the asphalt layer repeatedly until the wheel path deformation. Deformation on the wheel path is often found on flexible pavement, especially in areas with high temperatures. The wheel path deformation is formed when tensile stresses are generated due to high temperatures [10].

In this study, sample tests using WTM were carried out at varying temperatures of 27°C, 40°C and 60°C. The tool has a wheel load of $6.4 \pm 0.15$ kg/cm$^2$ which moves across the surface of the sample to reach 1,260 passes in a time of 60 minutes for a set of short cycles and can be extended by continuing
to test the standard WTM cycle as needed [11]. The sample for the WTM test was formed with a size of 300 mm x 300 mm x 50 mm with the density value referring to the density of the Marshall test sample. A mixture of virgin asphalt and RAP mixture for the WTM test has been established with an optimal asphalt content of 6%. The addition of NCR to the RAP of 1.25%, 2.5%, and 3.75% of the asphalt content.

3. Result and Discussion

3.1. Optimum Asphalt Content
All testing of virgin asphalt mixture and modified asphalt mixture have been carried out with an optimum asphalt content of 6% on aggregate asphalt mixture. The asphalt mixture has been designed according to standard Marshall mix design procedures. The specimen was compacted using 75 blows on each side of a cylindrical sample diameter of 101.6 mm and 63.5 cm thick. Physical properties of the mixture such as air void (VA), voids filled with asphalt (VFA), voids in Marshall mineral aggregate (VMA), stability and flow.

3.2. Deformation rate (DR) and Dynamic Stability (DS)
Figure 3 shows the changes in DR and DS values at temperature variations of 27°C, 40°C, and 60°C. From figure 3 it can be observed that the change due to the influence of temperature is quite significant, at a temperature of 27°C the slowest deformation speed and the highest Dynamic Stability is achieved at NCR addition of 1.25%, even the performance of virgin asphalt mixture is at the lowest. However, at an increase in temperature up to 40 °C there appears to be a change wherein the modified asphalt mixture with NCR is 2.5% as the best performing asphalt mixture. Even when the temperature is added up to 60°C the best modified asphalt mixture performance is achieved from the addition of 2.5% NCR. From these results it can be seen that the addition of NCR to the modified asphalt mixture for low temperature and high temperature requires different amounts of NCR content.

![Deformation Rate (mm/min) vs Dynamic Stability (cycle/mm)](image)

a. Temperature of 27°C.
b. Temperature of 40°C.

c. Temperature of 60°C.

**Figure 3.** Deformation Rate and Dynamic Stability on temperature of 60°C.

a. Rut depth on temperature of 27 °C.
3.3. Impact of temperature changes on rut depth of the asphalt mixture

From figure 4, it can be observed that there is a faster change in the virgin asphalt mixture, the initial cycle changes very quickly. Deformation continues to increase with increasing loading cycle until the end of the 1,260th cycle. Changes in temperature of 27°C and 60°C there was a significant change in the rut depth value in the mixture of virgin asphalt and each modified asphalt mixture. At 60°C the same performance was seen between virgin asphalt mixture and RAP asphalt mixture without NCR material. The addition of 2.5% NCR to asphalt content showed the best performance with deformation depth <1.5 mm in the 1,260th cycle. The addition of 2.5% NCR appears to be more stable to the effects of temperature changes of 40°C to 60°C.

4. Conclusion

From this research, we can conclude several conclusions about the use of RAP with NCR added as follows:

- The addition of WEO to the RAP mixture has increased the penetration value so that it can facilitate the RAP processing.
- The use of NCR in RAP mixture for low temperature and high temperature needs is different, at a temperature of 27°C the addition of NCR 1.25% shows the best performance results.
- At a temperature of 60°C has shown a very significant change is the addition of NCR 2.5% seems the most stable due to the impact of rising temperatures.
- The addition of NCR to the RAP mixture has shown better performance compared to the virgin asphalt mixture or RAP asphalt mixture without NCR.

Acknowledgments

This research was funded by the Direktorat Riset dan Pengabdian Masyarakat Universitas Indonesia through the PIT-9 Grant 2019, funded by contract no. NKB-0076/UN2.R3.1/HKP.05.00/2019. The authors thank the Pusjatan Bandung Laboratory of the Ministry of Public Works and Public Housing Republic of Indonesia, and the Structure and Material Laboratory of the Universitas Indonesia Civil Engineering Department.

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