Contribution of Nano Crumb Rubber on Recycled Asphalt Concrete As Pedestrian Paving Block

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Abstract. Stripping the road surface layers of asphalt concrete caused by various considerations that have been damaged by the aging process of asphalt. This stripping material will continue to grow in sufficient quantities if the recycling process is not utilized. The recycling process can be done by restoring the performance of asphalt or aggregate and can even occur both to meet the specifications required originally. In this research, asphalt concrete mixture has been used where the asphalt element has undergone an aging process so that it needs to be rejuvenated or softened. The addition of used oil has been used in the process of softening the hot Asphalt Concrete Wearing Course (ACWC) type. The process of increasing the performance of recycled blends has used Nano Crumb Rubber (NCR) material. The test results show that the ratio of the old asphalt content and used oil as a softener is obtained with a ratio of 11: 4 to obtain the required level of softening. This composition has produced a bitumen penetration value of 60, and the addition of NCR 2.5% and 5% to the asphalt content. Testing for recycled asphalt mixes is carried out with Marshall Test, Indirect Tensile Strength (ITS), and water absorption testing for recycled mixtures for paving blocks. The test results show the addition of NCR by the dry method has increased the strength of the mixture at both ambient and higher temperatures of 35 °C and 45 °C.

1. Introduction

Transportation infrastructure, especially road construction, has a significant influence on the environment. Road construction is a subsector that requires significant energy consumption because the total volume of material has been used on the road every year [1]. In Indonesia, flexible pavement is a type of road pavement that is mostly used on the highway. The many uses of asphalt have caused a lot of pavement waste called the Reclaimed Asphalt Pavement (RAP). This material is the residual waste of pavement that has been damaged or has expired. Not only from road construction, the high volume of vehicles that makes the use of tires increases can also cause waste of used tires. Negative impacts that require alternative steps to reduce these impacts. One of them is the utilization of road construction wastes such as RAP and used tires.

There are two main factors that influence the use of asphalt recycling (RAP) are economic savings and environmental benefits [2]. The use of RAP for road construction is also increasing because it is considered to be more cost-effective and included in environmental aspects that are sustainable [3]. Estimates of the average percentage of RAP use in asphalt mixtures have increased from 15.6 percent in 2009 to 20.4 percent in 2014 [4]. Based on research that has been done, asphalt mixes that use RAP with high levels can reduce energy use and greenhouse gases by 12.2% [5]. RAP is most commonly used as a substitute for virgin asphalt and aggregate material in recycled asphalt pavement, but is also
used as a stabilization of basic aggregates and road embankments [6]. One of the main problems in the use of RAP is that the material contained has experienced aging which can affect pavement performance [7]. Although the use of RAP helps in reducing the utilization of virgin asphalt binder and increases rut resistance, the old binder material in RAP is considered as a potential contributing factor responsible for pavement thermal failure and failure of fatigue cracking [8]. The use of high levels of RAP in asphalt mixtures tends to decrease fatigue resistance [2]. There is a need to improve properties on asphalt mixture with RAP to obtain a good quality asphalt mixture, one of which is the addition of crumb rubber. From the research that has been done, the addition of crumb rubber to the recycled asphalt mixture increases fatigue resistance [8].

Based on the problems and research results that have been described above, this study has conducted research on the effect of the use of reclaimed asphalt pavement and crumb rubber on the strength of the paving block. From the results of previous studies, the crumb rubber shape modification has changed into nano-sized material to determine its effect on the strength of the paving block. The use of reclaimed asphalt pavement and crumb rubber in the manufacture of paving blocks, based on previous studies where the mixture test showed results that tend to be lower when compared to asphalt mixtures with virgin material. So that the recycled asphalt mixture is more suitable for light weight roads such as pedestrian roads or bicycle lanes. Paving blocks can simplify the technique of utilizing recycled asphalt mixture because the mixture has been made in the form of paving blocks. Such a process will simplify the road construction process because it does not require the use of heavy equipment such as rollers and long processes such as the laying and compaction of asphalt mixtures.

2. Materials and Methods

1.1. Reclaimed Asphalt Pavement (RAP)
The recycled asphalt material that has been used is a material from the surface layer which is derived from the dredging of the Toll Road Jakarta Outer Ring Road (JORR). Asphalt mixture on the surface layer has Asphalt Concrete Wearing Course (AC-WC) specifications. RAP material tends to be of poor quality because the aggregate and asphalt contained has been damaged by the aging process. Therefore, it is necessary to add new aggregates and asphalt to improve the characteristics of recycled materials. Table 1 shows the results of characteristic tests for virgin asphalt and recycled asphalt material.

| No. | Type of Testing | Method | Indonesian Asphalt 60/70 | Virgin Asphlat | 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 |

1.2. Nano Crumb Rubber (NCR)
Crumb rubber is a material obtained from used tires in the form of small granules which are made in a certain size for material modification in asphalt mixtures. At present, the use of crumb rubber in asphalt mixes is increasing because it has the advantage of increasing the value of indirect tensile strength and skid resistance [9]. In addition, the addition of crumb rubber also increases fatigue resistance and deformation in road pavement [8].
There are two methods that can be used to mix crumb rubber into asphalt mixture, namely the wet and dry method. The wet method is done by first mixing crumb rubber with asphalt. The dry method is done by first mixing crumb rubber with aggregate. In this study, crumb rubber was modified to nano size to determine its effect on the mixture. The process of mixing nano crumb rubber (NCR) has been carried out by a dry method where NCR is added during the aggregate heating process.

1.3. Asphalt Mixtures
In this study, there are three types of specimens to be made namely two types of specimens for Marshall testing and one other type for Indirect Tensile Strength (ITS). There are 2 types of Marshall tests namely Marshall standard and Marshall immersion. To find the optimum asphalt content, variations of asphalt without nano crumb rubber with 0%, 5%, 5.5%, 6%, 6.5% and 7% are used. Then to find the optimum levels of nano crumb rubber with nano crumb rubber with variations in levels of 0%, 5%, 5.5%, 6%, and 6.5%. The third type is specimens with the best mix of asphalt and nano crumb rubber for paving block and ITS testing with temperature variations of 25 °C, 35 °C and 45 °C.

1.4. Marshall Test
Marshall testing is an asphalt heat mixture test to get the optimum asphalt content and to determine the characteristics of the mixture. This test is carried out to determine the stability and plasticity (flow) of the asphalt mixture. Stability is the ability of asphalt mixtures to accept loads up to plastic discharge. Plastic discharge is a change in shape caused by a load until it reaches the collapse limit.

1.5. Indirect Tensile Strength Test
Indirect Tensile Strength testing for asphalt mixtures is carried out by placing a load on the cylindrical specimen perpendicular to the diameter of the specimen with a certain rate of deformation and temperature. The maximum load when failure occurs is used for the calculation of Indirect Tensile Strength on the asphalt mixture. This test is also carried out to evaluate the quality of the asphalt mixture and is used to determine the potential damage due to water when the test results are obtained from different specimens, namely when immersed and not soaking the test specimen [10]

2. Result and Discussion

2.1. Modified Asphalt
The addition of NCR in the asphalt mixture was carried out by the dry mix method in which NCR was added during the heating process of RAP material. The variation of NCR content used in this test is 0%, 5%, 5.5%, 6%, and 6.5% as in table 2. From the results of the Marshall test it was known that the largest value of Void in Mineral Aggregate (VMA) with a NCR content of 6%. The value of Void Filled with Asphalt (VFA) for modified asphalt mixture is smaller than asphalt mixture without NCR. This is due to the VFA being replaced by the NCR. The VIM value of the modified asphalt mixture has a higher value than virgin asphalt mixtures, so that this mixture has properties more flexible and porous. The Marshall stability of the modified asphalt mixtures with NCR 2.5% has a higher strength. The effect of NCR content on the flow value of the modified asphalt mixture causes the flow value to decrease, while the Marshall quotient value is lower than the virgin asphalt mixture so that the modified asphalt mixture is more flexible. From the optimum NCR content that has been obtained, the variation of NCR content in asphalt mixtures in making ITS testing samples and paving blocks is 0%, 2.5%, and 5%. Table 3 shows the results of the Marshall test.

From table 3 and table 4 can be seen the change in the characteristics of asphalt mixture modification conditions before and after immersion. Table 5 has calculated the Residual Index value as a comparison of Marshall stability value from the effect of soaking for 24 hours at 60 °C. From this value, it can be seen the level of asphalt mixture susceptibility to temperature and water.
Table 2. Asphalt Modified Test Result.

| NCR content  | 0.00% | 5.00% | 5.50% | 6.00% | 6.50% | AC-WC Specification |
|--------------|-------|-------|-------|-------|-------|---------------------|
| Void in Mineral Agreggate (VMA) | 16.07 | 17.64 | 18.14 | 18.27 | 17.79 | Min. 15 |
| Void Filled With Asphalt (VFA) | 80 | 71.58 | 69.05 | 68.5 | 70.69 | Min.65 |
| Void in Mixtures (VIM) | 3.23 | 4.88 | 5.61 | 5.77 | 5.22 | Min.3.5 Max.5 |
| Marshall Stability (kg) | 1416.4 | 1315.6 | 1236.6 | 1166.2 | 1190 | Min.800 |
| Flow | 3.13 | 3.45 | 2.85 | 2.82 | 2.8 | Min.3 |
| Marshall Quotient (MQ) | 453.44 | 381.38 | 439.15 | 416.01 | 426.93 | Min.250 |

Table 3. Modified Asphalt Mixture Test Results.

| NCR content | 0% | 2.50% | 5% |
|-------------|----|-------|----|
| VMA (%)     | 16.07 | 17.14 | 17.5 |
| VFA (%)     | 80 | 74.07 | 72.22 |
| VIM (%)     | 3.23 | 4.46 | 4.88 |
| Stability (Kg) | 1416.4 | 1425.8 | 1315.6 |
| Flow (mm)   | 3.13 | 3.3 | 3.45 |
| Marshall Quotient (Kg/mm) | 453.44 | 432.24 | 381.38 |

Table 4. Marshall Immersion Test Results.

| NCR content | 0% | 2.50% | 5% |
|-------------|----|-------|----|
| VMA (%)     | 16.83 | 17.05 | 18.07 |
| VFA (%)     | 75.6 | 74.46 | 69.48 |
| VIM (%)     | 4.11 | 4.36 | 5.54 |
| Stability (Kg) | 1391.6 | 1396.7 | 1275.2 |
| Flow (mm)   | 2.95 | 2.88 | 2.98 |
| Marshall Quotient (Kg/mm) | 504.4 | 373.56 | 475.85 |

Table 5. Residual Index of Asphalt Mixtures.

| NCR (%) | Marshall Standard | Marshall Immersion | Residual Index (%) |
|---------|-------------------|--------------------|-------------------|
| 0       | 1416.42           | 1391.64            | 0.983             |
| 2.5     | 1425.76           | 1396.74            | 0.980             |
| 5       | 1315.64           | 1275.22            | 0.969             |

2.2. Indirect Tensile Strength (ITS) Test Results

Indirect Tensile Strength (ITS) testing has been carried out at the Bandung Road and Bridge Testing Center using the Universal Material Testing Apparatus (UMATTA), and the sample preparation process at the Structure and Material Laboratory of the Department of Civil Engineering, University of Indonesia. Sample measurements were carried out three times to obtain height and diameter data from the sample. Tests on test specimens were carried out by giving vertical direction shock loads to the sample.
The shock load given depends on the temperature of the test. For testing at 25 °C a shock load of 2000 N - 2500 N has been given, while for temperatures of 35 °C and 45 °C, the shock load given is 900 N - 1500 N. This loading is the result of a computer simulation based on Poisson theory, and the sample will deform in the horizontal direction, then the instrument will read the ability of the sample to return to its original condition or called deformation recovery. Figure 1 is the result of testing from Indirect Tensile Strength (ITS).

![Figure 1](image1.png)

**Figure 1.** Average Resilient Modulus Value with different temperatures.

From the figure 2, the greatest resilient modulus for 25 °C is in the virgin asphalt mixture without NCR. However, resilient modulus values with 2.5% NCR content have higher values at the test temperature at 35 °C and 45 °C. This has shown that the modified asphalt mixture with NCR has a stronger ability to higher temperatures. However, on the contrary the addition of 5% NCR has reduced the value of resilient modulus. This shows the presence of optimum NCR content in the asphalt mixture at 2.5%.

Figure 1, the lowest horizontal deformation value in the virgin asphalt mixture at a test temperature of 25 °C. However, for testing at 35 °C and 45 °C, the lowest deformation value was at 2.5% NCR content. Whereas for specimens with 5% NCR content the value of horizontal deformation is higher. This shows that there is an optimum limit of NCR content in the asphalt mixture. The chart above shows that the NCR content is 2.5% stronger resisting horizontal deformation at high temperatures.

![Figure 2](image2.png)

**Figure 2.** Total Horizontal Deformation with different temperatures.
2.3. Absorption Paving Block Test Results

Paving block testing is carried out to determine the effect of RAP material and NCR added material on the characteristics of paving blocks. The process of making RAP paving block samples is done differently from cement concrete paving blocks. The process of making this RAP paving block refers to the making of a Marshall test sample. RAP material is heated to 120 °C, the next step is mixing with NCR at 150 °C. The process of compacting the modified RAP asphalt mixture is incorporated into the paving block mold. Compaction is carried out when the temperature is in the range of 110 °C-120 °C. Compaction is done manually by referring to Marshall compaction which does 75 collisions for each side. Compaction is carried out by means of an iron plate and after compacting the paving blocks are removed from the mold for testing the absorption rate.

Table 6. Test Results of Paving Block Water Absorption.

| NCR content | Sample 1 | Sample 2 | Sample 3 | Average |
|-------------|----------|----------|----------|---------|
| 0%          | 2411.2   | 2381.2   | 2401.2   | 2.26    |
| Water weight (kg) | 2355.6   | 2322     | 2357.4   |         |
| Water absorption (%) | 2.36     | 2.55     | 1.86     |         |
| 2.5%        | 2423.4   | 2409     | 2409     | 2.02    |
| Water weight (kg) | 2373     | 2353     | 2372.2   |         |
| Water absorption (%) | 2.12     | 2.38     | 1.55     |         |
| 5%          | 2402.4   | 2422.4   | 2402.6   | 1.34    |
| Water weight (kg) | 2368.8   | 2388.8   | 2374     |         |
| Water absorption (%) | 1.42     | 1.41     | 1.2      |         |

From table 6, it can be seen that the relationship between the value of water absorption and NCR content is inversely proportional. This is indicated by the increasing NCR content in the modified asphalt mixture, the water absorption value will be smaller. This is due to the more NCR content, the more cavities that are filled by NCR. So that the absorption of water in the mixture becomes lower. Based on the Indonesian National Standard (SNI), the three specimens have met the standard, namely the water absorption value is below 8%.

In this study, testing for paving blocks is different from paving blocks made of concrete material. Paving block forming material used in this study is a mixture of asphalt so that the material will have different characteristics with concrete paving blocks where to determine the strength of the compressive strength test. As for paving blocks with asphalt binding material, testing is carried out to determine the characteristics and strengths carried out by Marshall test and Indirect Tensile Strength (ITS) tests.

3. Conclusion

Based on research and analysis conducted, the conclusions of this study are as follows.

- The asphalt content contained in the RAP material is 5.79% obtained from the extraction process. The average gradation of reclaimed asphalt pavement (RAP) aggregate material is still within the ACWC specifications which indicates that the RAP material has a good aggregate gradation and there is no addition of new aggregate to RAP material.
- The value of optimum asphalt content (KAO) with new material obtained from Marshall test results is 6%. So that the new asphalt content that needs to be added to the RAP material is 0.205%.
Optimum nano crumb rubber (NCR) content obtained from the results of the Marshall test and Indirect Tensile Strength (ITS) and paving block testing is 2.5%.

From the test results of water absorption, the results show that the recycled asphalt mixture with nano crumb rubber (NCR) as a paving block material has a low absorption rate of less than 8%.

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References

[1] Yang R, Kang S, Ozer H, & Al-Qadi I L, 2015, Environmental and Economic Analysis of Recycled Asphalt Concrete Mixtures Based On Material Production and Potential Performance. Resource, Conservation, and Recycling.

[2] Izaks R, Haritonous V, Klasa I, & Zaumanis M, 2015, Hot Mix Asphalt With High RAP Content, Procedia Engineering, Volume 114, Pages 676-684.

[3] Arshad M, & Ahmed M F, 2017, Potential use of reclaimed asphalt pavement and recycled concrete aggregate in base or subbase layer of flexible pavement. Construction and Building Materials, 83 - 97.

[4] Zhao S, & Liu J, 2018, Using Recycled Asphalt Pavement In Construction of Transportation Infrastructure : Alaska Experience, Journal of Cleaner Production, Volume 177, Pages 155-168.

[5] Aurangzeb Q, Al-Qadi I, Ozer H, & Yang R, 2014, Hybrid life-cycle assessment for asphalt mixtures with high RAP content, Resources, Conservation and Recycling, Volume 83, Pages 77-86.

[6] Sultan S A, & Guo Z, 2016, Evaluating the performance of sustainable perpetual pavements using recycled asphalt pavement in China. International Journal of Transportation Science and Technology.

[7] Chen X, & Wang H, 2018, Life cycle assessment of asphalt pavement recycling for greenhouse gas emission with temporal aspect. Cleaner Production, 148 - 157.

[8] Xiao F, Amirkhanian S N, Shen J & Putman B, 2009, Influence of crumb rubber size and type on reclaimed asphalt pavement (RAP) mixtures, Construction and Building Materials 23, 1028–1034.

[9] Eskandarsefat S, Sangiorgi C, Dondi G & Lamperti R, 2018, Recycling Asphalt Pavement and Tire Rubber : A Full Laboratory and Field Scale Study, Construction and Building Materials, Volume 176, Pages 283-294.

[10] Vasconcelos K, Bernucci L B & Chaves J M, 2012, Effect of Temperature on the Indirect Tensile Strength Test of Asphalt Mixtures, 5th Eurasphalt & Eurobitume Congress, Istanbul.