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Laboratory Evaluation of Asphalt Concrete - Wearing Course (AC-WC) with Crumb Rubber Mixture

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Abstract

This study aims is to measure the performance of a mixture of Asphalt Concrete - Wearing Course (AC-WC) with addition of crumb rubber using a dry process, where crumb rubber as an aggregate substitution of fraction no. 50 with a mixture variation of 0%, 25%, and 50%. The method used in this research is the experimental method in the laboratory. Primary data collection is done through testing of aggregates, asphalt, crumb rubber, and mixtures. Hot mix design used Marshall test to obtain Optimum Bitumen Content (OBC). Laboratory test in OBC conditions obtain consist of Resilient Modulus test used Dynamic Testing System (DTS) at 25°C, 35°C, and 45°C and rut depth test used Hamburg Wheel Tracking (HWT) at temperatures 45°C and 60°C. The results of addition of crumb rubber content to the mixture can increase the value of OBC and reduce the value of Marshall stability, the percentage of 50% crumb rubber obtained highest OBC and the lowest Marshall stability. The crumb rubber content in the mixture lowers the value of Modulus Resilient, AC-WC with 0% crumb rubber has the highest value. At a temperature of 60°C, 25% crumb rubber content in the mixture reduces the rut depth value. Based on the Marshall stability, Resilient Modulus, and rut depth values, then the crumb rubber content to replace aggregate fraction no. 50 in the AC-WC gives the highest value is 25% in laboratory test.

Keywords: AC-WC, crumb rubber, resilient modulus, hamburg wheel tracking.

Abstrak

Penelitian ini bertujuan untuk mengukur kinerja campuran laston lapis aus (AC-WC) yang dimodifikasi dengan serbuk ban bekas (crumb rubber) menggunakan proses kering, dimana crumb rubber sebagai subtitusi agregat fraksi no. 50 dengan variasi campuran 0%, 25%, dan 50%. Metode yang digunakan dalam penelitian ini adalah metode eksperimen di laboratorium. Pengumpulan data primer dilakukan melalui pengujian terhadap agregat, aspal, crumb rubber, dan campuran. Perencanaan campuran beraspal panas menggunakan metode Marshall untuk mendapatkan Kadar Aspal Optimum (KAO). Pengujian laboratorium pada kondisi KAO yang didapat terdiri atas pengujian Modulus Resilien dengan menggunakan alat Dynamic Testing System (DTS) pada temperatur 25°C, 35° C, dan 45°C serta pengujian rut depth dengan menggunakan alat Hamburg Wheel Tracking (HWT) pada temperatur 45°C dan 60°C. Dari hasil pengujian penambahan crumb rubber pada campuran dapat meningkatkan nilai KAO dan menurunkan nilai stabilitas Marshall, dimana pada persentase 50% crumb rubber didapat KAO tertinggi dan stabilitas Marshall terendah. Penambahan crumb rubber dalam campuran menurunkan nilai Modulus Resilien, dimana campuran AC-WC dengan 0% crumb rubber memiliki nilai yang paling tinggi. Selain itu, pada temperatur 60°C penambahan 25% crumb rubber dalam campuran memperkecil nilai rut depth. Berdasarkan nilai stabilitas Marshall, Modulus Resilien, dan rut depth tersebut maka kadar crumb rubber untuk pengganti agregat fraksi no. 50 yang memberikan nilai terbaik pada campuran AC-WC adalah 25% sesuai dengan pengujian di laboratorium.

Kata-kata kunci: AC-WC, *crumb rubber*, modulus resilien, *hamburg wheel tracking*.

1. Introduction

Research on the use of crumb rubber needs to be done because the waste disposal of crumb rubber, in the long run, will have a negative impact on the environment. The use of crumb rubber, either as an additive or as an aggregate replacement in asphalt mixtures or as a modified asphalt, is an important innovation to do these days. These efforts are expected to significantly reduce the amount of waste disposal from used tires

Diterima 12 November 2019, Direvisi 15 November 2019 Diterima untuk dipublikasikan 9 Desember 2019

and help protect the environment. In addition, the use of crumb rubber in asphalt mixtures is also expected to improve the quality of the asphalt mixtures that have been used so far.

There are several types of hot mix asphalt, but in this research, the type of hot mix asphalt reviewed was the AC-WC, which is a pavement layer that interacts directly with vehicle tires. The AC-WC is a layer that is waterproof, resistant to weather and has a skid resistance. This layer must be able to accept all types of workloads. In general, the AC-WC is made using asphalt binder so that it produces a waterproof coating with high stability and long durability. However, there are weaknesses in flexibility, durability and susceptibility to fatigue cracks, so the use of crumb rubber as an aggregate replacement is expected to overcome the existing weaknesses. According to Lestari (2015), crumb rubber is an additive that can be used in asphalt mixtures.

According to Nguyen at al. (2017), compared to conventional asphalt, crumb rubber has the advantage of being more durable and having a more elastic surface. The results of the study indicate that the use of crumb rubber on highway pavement has been proven to reduce rutting on new pavement, increase skid resistance and pavement age, and reduce noise levels. Based on a study conducted by Ananda (2009) Aggregate replacement using crumb rubber can increase the asphalt mixture's resistance to water so it can reduce road damage, with the optimum crumb rubber percentage of 25%.

Based on this phenomenon, a study was carried out to measure the performance of a mixture of Asphalt Concrete - Wearing Course (AC-WC) modified with crumb rubber using a dry process, where the crumb rubber was an aggregate replacement of fraction no. 50, based on crumb rubber sieve analysis test. The variation of the mixture used in this study follows the optimum percentage in the previous research of 25%. As a comparison, the addition of twice the optimum percentage was done at a percentage of 50% crumb rubber and it was also compared with conventional asphalt at a percentage of 0% crumb rubber.

The purpose of this study is to measure the performance of a mixture of Asphalt Concrete - Wearing Course (AC-WC) modified with crumb rubber using a dry process, where the crumb rubber was an aggregate replacement of fraction no. 50 with mixture variations of 0%, 25%, and 50%.

In this study, further testing was carried out to determine the value of Resilient Modulus from crumb rubber-modified asphalt mixture with repeated load using the Dynamic Testing System (DTS) that refers to ASTM D4123-82. Other than that, a test using the Hamburg Wheel Tracking (HWT) which refers to the AASHTO T324-04 testing standard was carried out. This test aimed to measure rutting resistance by comparing the rut depth and the number wheel passes from a crumb rubber-modified asphalt mixture.

2. Material and Laboratory Tests

2.1 Asphalt

Asphalt is a viscoelastic material, whose physical properties depend on the temperature and loading duration. During mixing and compaction, the asphalt is viscous. But during the service period, the asphalt is viscoelastic. It is this viscoelastic nature that enables asphalt to cover and hold the aggregate in place during the production process and its service period. Basically, asphalt is made of a hydrocarbon chain called bitumen, therefore asphalt is often called a bituminous material (Francnken, 1998).

In this test, the asphalt used was Asphalt Pen 60/70 (Shell). Asphalt basic rheology test was carried out to determine the characteristics of asphalt. From the test results, all values met the 2018 Bina Marga General Specifications.

2.2 Aggregate

Aggregate is a constituent which has a very important role in transportation infrastructure, especially in the case of road pavement. The aggregate requirement in the mixture ranges from 90% -95% of the mixture's total weight, or 75% -85% of the mixture's volume. (Shell Bitumen, 2015).

ASTM defines aggregate as a material consisting of solid minerals, in the form of large mass or fragments including sand, gravel, coarse aggregate, blast furnace slag, and aggregate dust. Before being used as a mixture in pavement, an aggregate examination must be carried out in the laboratory to determine its characteristics. To determine a good aggregate, the aggregate must be classified based on size, cleanliness, grain shape, toughness, strength, porosity and surface texture, composition, and its viscosity to asphalt.

In this test, the aggregate used was a natural aggregate from Palembang, South Sumatra. The test of aggregate properties was carried out to determine aggregate characteristics. From the test results, all values met the 2018 Bina Marga General Specifications.

2.3 Crumb rubber

Crumb rubber is an environmentally friendly product because it is used from used rubber and does not dissolve in soil or ground water. In addition to reducing the amount of rubber waste in the environment, reusing waste from certain rubber products may reduce the price of rubber as an important component in determining the price of the finished products. In certain products, the use of rubber aims to provide certain desired properties.

Some characteristics of crumb rubber may affect the nature of the asphalt-crumb rubber mix. The physical characteristics of rubber include:

1. Particle size (gradation)
2. Shape (angular or elongated)

Diterima 12 November 2019, Direvisi 15 November 2019 Diterima untuk dipublikasikan 9 Desember 2019

3. Surface texture (affected by the milling method
4. The presence of impurities (contaminant)

In this test, the test was carried out in a dry process, where the crumb rubber was mixed with aggregates before adding asphalt binder to the mixture.

2.4 Marshall and absolute density

The hot asphalt mix design method to determine the performance of AC-WC that is commonly done in Indonesia is the Marshall method. From this test, stability and flow values are obtained, and then the stability and fatigue ratio (Marshall Quotient) and other volumetric measures will be calculated. In this test, the Optimum Asphalt Content (OAC) can also be analyzed later.

Absolute density is the highest (maximum) density that can be achieved by a mixture until the condition where the mixture cannot become even denser is reached. This absolute density is a refinement of the conventional Marshall method. For a heavy traffic condition, the conventional Marshall sets test specimens compaction with 2 x 75 collisions with a void in mix limit of 3% - 5%. The results of the quality control test indicate that the appropriateness of control parameters in the field is often not met to achieve the requirements in the specifications so that the performance of road pavement is not achieved.

2.5 Stiffness modulus

This test was conducted to determine the value of the resilient modulus of the asphalt mixture. Resilient modulus is the level of elasticity and stiffness that is theoretically obtained from the relationship between stress and strain of a material. Resilient modulus can be used, among others, as an assessment to predict stress, strain and displacement, and can also be used as a pavement design approach and to evaluate pavement performance.

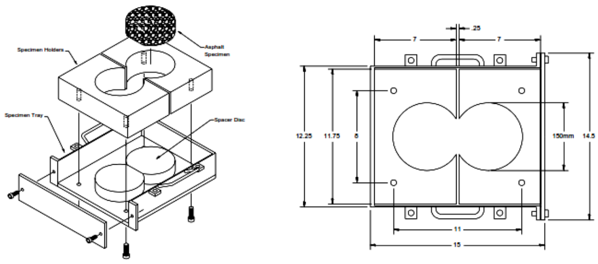
In this study, the value of the mixture's resilient modulus was calculated with repeated load using a Dynamic Testing System (DTS) that refers to ASTM D4123-82 / AASHTO TP31. This test is a test that does not damage the test specimens because the load is relatively small. The Dynamic Testing System (DTS) tool consists of a Control and Data Acquisition System (CDAS) device, personal computer and an integrated software.

2.6 Rutting resistance

This test was conducted to determine the value of the Ruth Depth (RD), and the Number of Passed to Failure (Nf) of the asphalt mixture. The test tool used was the Hamburg Wheel Tracking test.

Hamburg Wheel Tracking was developed in Germany and can be used to evaluate the potential for rutting and stripping. Hamburg Wheel Tracking (HWT) test for Hot Mix Asphalt (HMA) refers to the AASHTO T324 04. The test specimens were one rectangular test specimen or two cylindrical test specimens. The specimens were compacted using a Superpave Gyratory Compacted (SGC) compactor by locking the density obtained from the Marshall result with a VIM value of 7 ± 2% (AASHTO T 324 04). The test was carried out in a laboratory in a room with temperatures adjusted to field conditions.

Hamburg Wheel Tracking Test is a simulation, where the wheel load moves back and forth across the test specimens. This test was carried out with two cylindrical specimens with a diameter of 150 mm and a thickness of 60 mm. **Figure 1** shows an illustration of the installation and dimensions of the test specimen. A wheel with a width of 1.85 inches (47 mm) and a diameter of 8 inches (203.2 mm) moves back and forth on a soaked sample for 20,000 passes (or up to 20 mm deformation depth) using a load of 158 lb ± 1.0 lb (705 ± 4,5N).



(a) (b)

Figure 1. (a) Illustration of cylindrical test specimen installation configuration; (b) Dimensions of thencylindrical test specimen installation configuration (Tsai, 2016)

From the rutting resistance test using the Hamburg Wheel Tracking, the value of Rut Depth and Stripping Inflection Point (SIP), which is the number of wheel passes between creep slope and stripping slope, where after this point, stripping damage begins to dominate the performance until a collapse occurs, or in this study, is called the Number of Passed to Failure (Nf), as illustrated in **Figure 2** below.

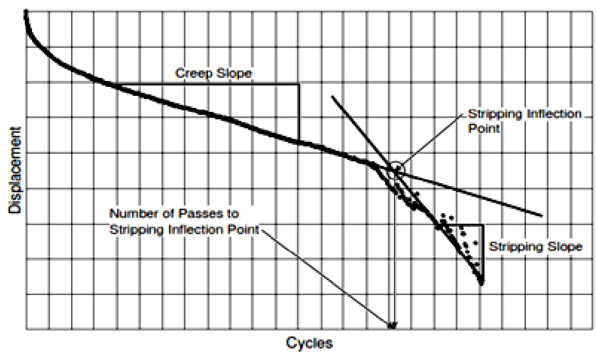


Figure 2. Rut depth versus the number of wheel passes curve conformed with AASHTO T 324

From **Figure 2**, the curve is divided into 3 regions. The first one is the creep slope where the damage (rutting) due to the load of the wheel track that occurs is still moving slowly up to a certain point, or in the curve, is called the Stripping Inflection Point (SIP). After SIP, the damage that occurs is dominated by stripping and

Diterima 12 November 2019, Direvisi 15 November 2019 Diterima untuk dipublikasikan 9 Desember 2019

eroding of aggregates where the mixture tends to begin to lose fine aggregates and coarse aggregate particles can become detached. This last area is called the stripping slope where the specimen fails rapidly until the specimen is unable to resist rutting (failure).

Higher values of creep slope, Striping Inflection Points (SIP), and stripping slope indicate less damage. The City of Hamburg determined the rut depth of less than 4 mm after 20,000 passes. Previous research found that this specification is very heavy for pavements in Colorado. Rut depth of less than 10 mm after 20,000 passes may be more acceptable. Additionally, the test temperature must be adjusted based on the environment in which the mixture will be placed. (Yildirim, 2001)

3. Research Methodology

The method used in this research was the experimental method in the laboratory. Primary data collection was done through testing of aggregates, asphalt, crumb rubber, and mixtures. This research was carried out in the laboratory of the Balai Besar Pelaksana Jalan Nasional V (BBPJN V) Palembang and the Bandung Institute of Technology (ITB) laboratory. Broadly speaking, this research can be seen from the flowchart in **Figure 3**.

4. Data Presentation and Analysis

In this test, codes were used for each variation of the mixture and are presented in **Table 1**.

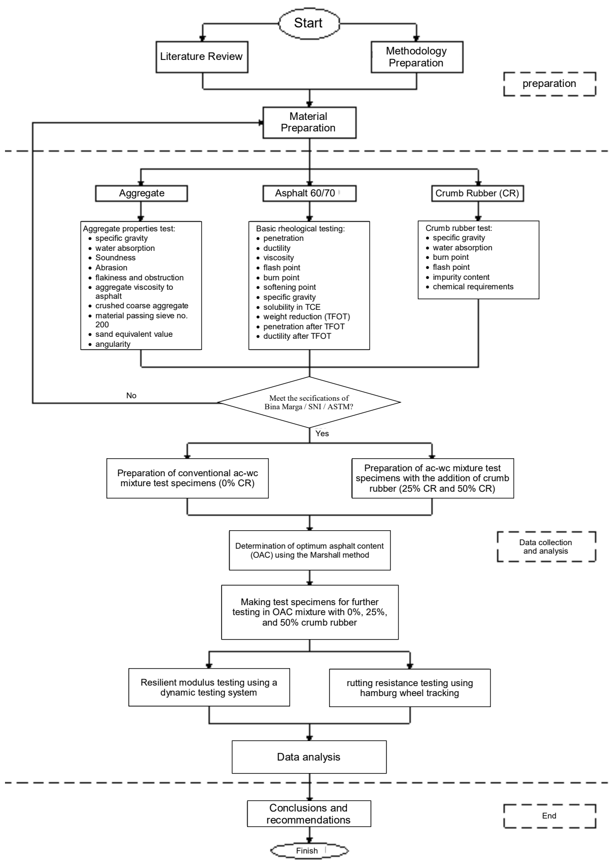


Figure 3. Research fowchart

Table 1. Mixture variation of crumb rubber

Mixture Type	Crumb Rubber Percentage
AK_0	0 %
AK_1	25 %
AK_2	50 %

4.1 Optimum asphalt content

The optimum asphalt content is an asphalt content which produces a mixture that fulfills all elements of the Marshall parameters, including VIM Refusal. VIM Refusal can reduce the percentage of optimum asphalt content in the mixture because it considers the conditions in which the mixture in the pavement experiences further compaction by the traffic load. The comparison of optimum asphalt contents between mixtures can be seen in **Figure 4**.

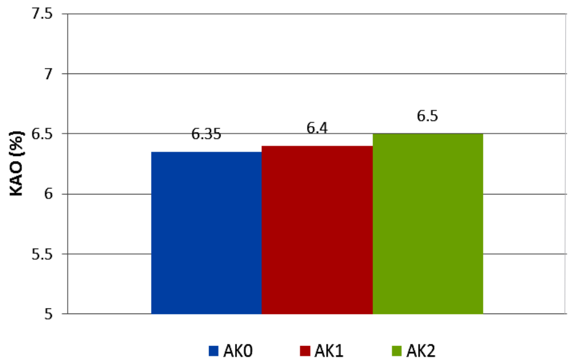


Figure 4. Optimum asphalt contents comparison

Based on **Figure 4**, the OAC value of the mixture increased with the increasing percentage of crumb rubber in the mixture. The increase in the amount of crumb rubber in the mixture was directly proportional to the increase in OAC needed. That is because the crumb rubber acts as an additional aggregate in the mixture so that more asphalt content is needed to fill the cavities/pores in the mixture or to wrap and tie the aggregate.

4.2 Marshall stability

Stability is an empirical parameter to determine the ability of road pavement in receiving traffic loads without permanent changes in shape such as waves, grooves and bleeding (Asphalt Institute, 1989). Stability value provisions according to the 2018 Bina Marga General Specifications for AC-WC is limited to a minimum of 800 kg and according to the 2017 Bina Marga Special Specifications for the modified AC-WC with crumb rubber, the minimum is 1000 kg. A comparison of the stability values of each mixture is presented in **Figure 5**.

Based on **Figure 5**, the stability in the modified mixture was lower than in the conventional mixture. This was caused by the surface shape of the crumb rubber particles which is finer and softer compared to the surface of the aggregate particles, thereby reducing the viscosity of the asphalt to the mixture. In addition,

Diterima 12 November 2019, Direvisi 15 November 2019 Diterima untuk dipublikasikan 9 Desember 2019

due to the role of crumb rubber as a replacement for aggregate in the mixture, the crumb rubber does not work to harden the asphalt but softens the mixture instead.

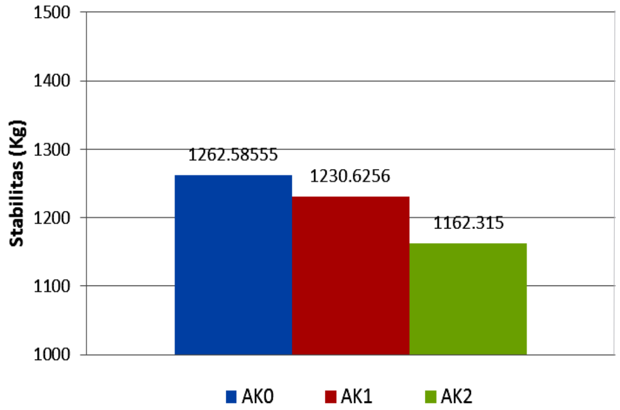
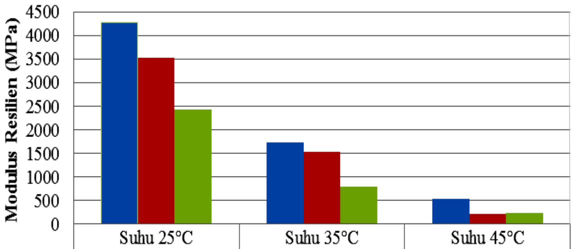


Figure 5. Comparison of the stability values

4.3 Resilient modulus test

Resilient modulus is a modulus of elasticity based on recoverable strain. This terminology is used because asphalt mixture is a material that is not perfectly elastic. The viscoelastic property of the asphalt mixture causes the resilient modulus to change depending on the temperature and the time of loading received. The higher the temperature, the lower the resilient modulus. This is because at high temperatures the asphalt will become more liquid and not solid anymore, so the asphalt's ability to bind will be greatly reduced which makes the bond between the aggregates in the mixture not interlocking.

In addition to the test temperature, the hardness of the binder (asphalt) and aggregate characteristics also affect the value of the resilient modulus of an asphalt mixture. Resilient modulus test in this study was conducted at test temperatures of 25°C, 35°C and 45°C. The test result at a temperature of 45°C shows a smaller resilient modulus value compared to the test at temperatures of 25°C and 35°C. The test results were shown in **Figure 6**.



	Suhu 25°C	Suhu 35°C	Suhu 45°C
AK0	4273	1728	525
AK1	3534	1528	214
AK2	2423	784	240

Figure 6 Comparison of the mixture's resilient modulus values for temperature variations

From **Figure 6**, the Resilient Modulus value of each type of mixture decreased with increasing temperature. The picture also shows that the Resilient Modulus value for the mixture that was modified with crumb rubber was lower than the mixture without crumb rubber (conventional). Resilient Modulus value for the AK_2 mixture was lower than the AK_1 mixture, except at the temperature of 45°C. However, the two mixtures show a value that is not too far away. This is because the higher percentage of crumb rubber will correct the gradation of the mixture to become finer so that more asphalt is needed and at higher temperatures, the mixture is not stiffer.

The resilient modulus value can not only be determined by a mechanistic method using the DTS tool but can also be determined by empirical methods using formulas that have been generated through experiments in the laboratory.

Theoretical calculations aim to predict the value of the mixture stiffness (S_{mix}) and compare it with the value of the Resilient Modulus obtained from the Dynamic Testing System tool.

The prediction of Smix value in this study was carried out by the Asphalt Institute Method. The Smix comparison can be seen in **Figure 7** below.

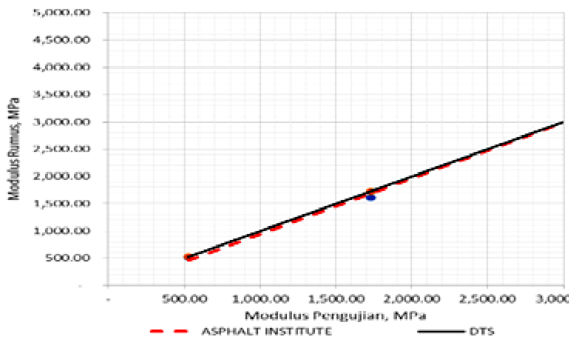


Figure 7 Comparison of the mixture's resilient modulus values and theoretical calculations

In general, although there are differences, both modulus testing using DTS and theoretical predictions produce modulus that gets smaller when the temperature rises.

4.4 Rutting resistance test

In this study, the Hamburg Wheel Tracking test was conducted to evaluate the rutting resistance characteristics of the mixture according to the percentage of crumb rubber. The rutting resistance test in this study was carried out at a test temperature of 45° C and 65°C.

Using the data from the Hamburg Wheel Tracking test and the curve installation technique, the values of rut depth, creep slope, number of passed to failure (Nf), and rut depth failure were obtained. The results can be seen in **Table 2**.

The Hamburg Wheel Tracking tester automatically recorded deformation (mm) along the specimen for each wheel track. **Figure 8** and **Figure 9** shows the comparison of rut depth and the number of passes at each temperature.

Diterima 12 November 2019, Direvisi 15 November 2019 Diterima untuk dipublikasikan 9 Desember 2019

Table 2. Rutting resistance value

Jenis Campuran	Suhu Uji (°C)	N_f	*Creep Slope* (Lintasan /mm)	*Rut Depth Failure* (mm)	*Rut Depth* (mm)
AK_0	45	5962	1556	7,15	3,25
	60	2290	550	5,20	3,85
AK_1	45	4846	2133	6,75	3,50
	60	3440	781	5,42	3,00
AK_2	45	3796	857	7,00	4,75
	60	2916	591	7,65	5,30

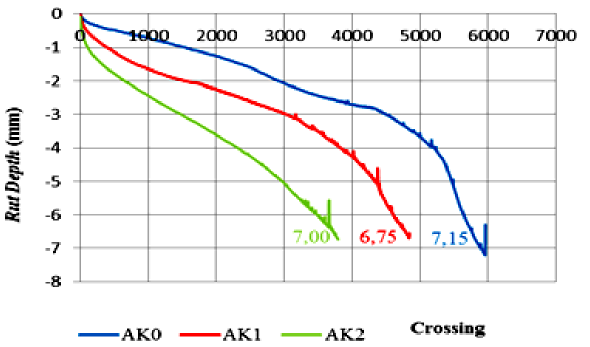


Figure 8. Comparison of the rut depth value and the number of passes in each mixture at the temperature of 45°C

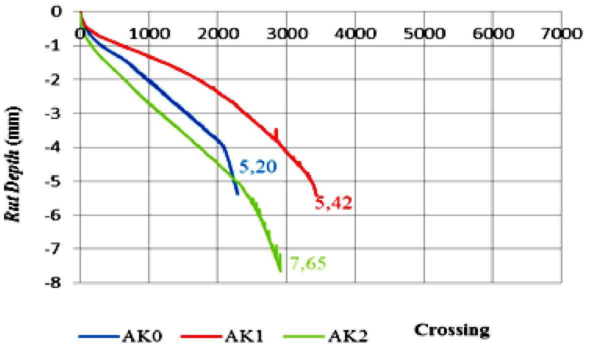


Figure 9. Comparison of the rut depth value and the number of passes in each mixture at the temperature of 60°C

From **Figure 8**, the track at a temperature of 45°C decreases as the crumb rubber percentage increases. From the picture, it can also be seen that the number of passes for the mixture modified with crumb rubber is less than the number of passes for the mixture without crumb rubber (conventional). This means that at a temperature of 45°C, the mixture which was modified with crumb rubber has a lower resistance to rutting compared to the conventional mixture. Meanwhile, at a temperature of 60°C (**Figure 9**), the number of passes for all mixtures is smaller than the number of passes at 45°C. However, the conventional mixture has a smaller number of passes compared to the one modified crumb rubber. This is because when the mixture begins to lose fine aggregates, the crumb rubber which functions as a replacement for aggregate is not easily eroded because it has more flexible properties. The highest number of passes using crumb rubber is in the AK_1 mixture.

Test results at 45°C and 60°C show different rut depth values. The test results are shown in **Figure 10**.

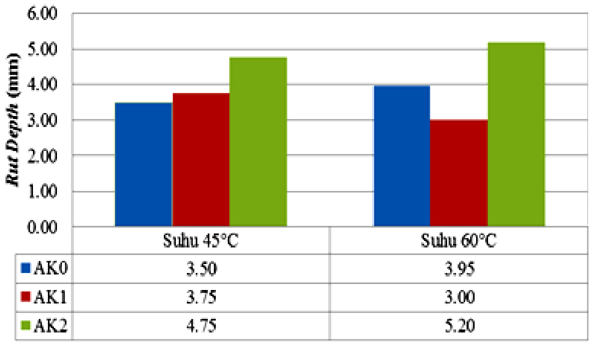


Figure 10. Comparison of the rut depth values and temperature variations

Rut depth is the amount of deformation in each sublayer. At 45°C, the rut depth value increased. This proves that the previous Resilient Modulus value shows that the mixture with crumb rubber modification had a low rutting resistance. While at a temperature of 60°C, it shows that the performance of the modified mixture with 25% crumb rubber was better than the mixture with 0% and 50% crumb rubber. This was indicated by a small rut depth value of 3.00 mm and a long pass/track.

In this test, the value of rut depth at the time of collapse (failure) was also obtained. The results can be seen in **Figure 11** and **Figure 12**.

At a temperature of 45°C, the number of passed failure decreased with the addition of crumb rubber, but the addition of 25% crumb rubber produced the lowest rut depth. At 60°C, the crumb rubber content of 25% had a high rutting resistance shown by the number of passed failure which was longer and the rut depth that was smaller than the mixture with 0% and 50% crumb rubber.

Based on the recommendations, the AC-WC with addition of crumb rubber can be seen from the creep slope value. SIP and rut depth at 45°C and 60°C for the AK1 mixture with 25% crumb rubber shows an optimum value.

5. Conclusions

In general, the results and analysis of the test conducted can be concluded as follows:

1. The addition of crumb rubber can increase the use of asphalt in making mixtures and reduce the Marshall stability and Resilient Modulus values.
2. At high temperatures, crumb rubber in the mixture reduces the rut depth value and increases resistance to an increased number of passes, thereby extending the pavement life.
3. Based on the values of Marshall Stability, Resilient Modulus, rut depth, and the number of passes, in this study, the best crumb rubber content in the AC-WC to replace the aggregate fraction no. 50 is 25%.

Diterima 12 November 2019, Direvisi 15 November 2019 Diterima untuk dipublikasikan 9 Desember 2019

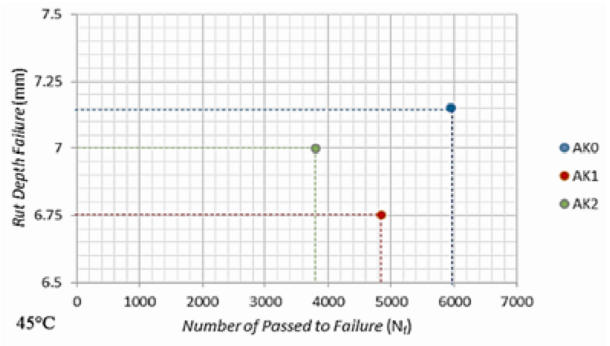


Figure 11. Comparison of the rut depth value and the number of passed to failure at 45°C

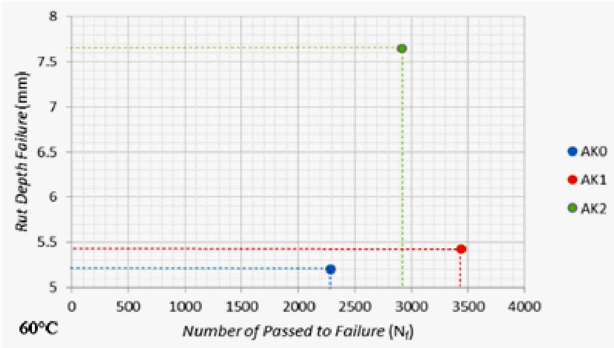


Figure 12. Comparison of the rut depth value and the number of passed to failure at 60°C

6. Recommendation

Based on the results of the study, some suggestions are suggested: further test needs to be done with the percentage of crumb rubber such as 20% and 30% as a replacement for aggregates in different fractions to find out the optimum value of crumb rubber in AC-WC.

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