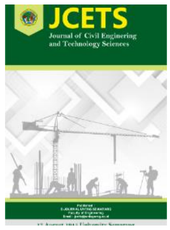
**Journal of Civil Engineering and Technology Sciences**
Vol. 03, No. 02, Page 1-13

**Journal of Civil Engineering and Technology Sciences**
**Universitas 17 Agustus 1945 Semarang**
Jurnal Homepage : https://jurnal2.untagsmg.ac.id/index.php/JCETS




# The Effect of Adding Teak Charcoal as a Filler on the Performance of the Asphalt Concrete-Wearing Course (AC-WC)

**Lucky Setyawan[1], Ibnu Sholichin[2], Nugroho Utomo[3]**

[1,2,3] University of Pembangunan Nasional "Veteran" Jawa Timur
Author's Correspondance: Ibnu Sholichin
Email: ibnu.ts@upnjatim.ac.id

**Abstract.**

The filler in asphalt concrete layers usually uses Portland cement, whose raw materials are limestone and clay, these resources are limited and cannot be renewed. Therefore, teak wood charcoal can be an alternative filler. Charcoal contains non-polar carbon compounds, such as asphalt, which hold different particles together with adhesive properties. So, this research is expected to be able to use teak wood charcoal as a filler by the General Specifications for Bina Marga 2018 2nd Revision. This research uses variations in filler levels of 0%, 1%, 2%, 3% and 4%. Based on the Marshall test results, the optimum asphalt content value was 6.40% and the optimum filler content value was 0.58%. The addition of teak charcoal as a filler increases the stability, Marshall Quotient, VIM and VMA values, but reduces the flow and VFA values. In conclusion, the addition of teak charcoal as a filler to the AC-WC mixture can increase the strength of the road pavement, but excessive use can make the road pavement porous and damaged.

**Keywords:** Filler; Teak Wood Charcoal; Marshall.

## 1 Background

Roads have a vital role in supporting the economic development of society by ensuring that needs are met through the distribution of goods and services (Utomo et al., 2020). There are several types of layers in asphalt concrete layers, and one of them used in this research is the AC-WC layer. The AC-WC layer is located at the top of the road pavement layer, so it is the first layer to support the vehicle load.

Selecting the right asphalt, aggregate and filler materials is an important factor in improving road pavement quality with asphalt concrete mixtures. Fillers can be non-plastic materials such as stone

Received 20 June 2024 , Revised 12 August 2024, Accepted for publication 31 October 2024
 p-ISSN: 2963-7244 e-ISSN: 2964-6960 , DOI: https://doi.org/10.56444/jcets.v3i2

dust and cement (Rumbyarso, 2022). The primary raw materials for making cement are limestone and clay, natural resources whose availability is limited and cannot be renewed. Therefore, alternative materials, such as teak wood charcoal, are needed to replace cement as filler.

According to the Central Statistics Agency, in 2020, teak wood production was 472,725.12 $m^3$, in 2021 teak wood production was 482,510 $m^3$, and in 2022, teak wood production was 494,997 $m^3$. Based on this data, teak wood has increased on average by 11,125.94 $m^3$ every year (Badan Pusat Statistik, 2023). Despite the increase, teak wood production is less than that of wood in general. Therefore, teak wood waste must be utilized optimally. One use of teak wood waste obtained from furniture entrepreneurs is to use it for charcoal.

Charcoal is produced from burning wood at high temperatures, so most of its chemical components are carbon (Salim, 2016). In 2000, Indonesia exported 29,867 tons of charcoal, of which 15.96% was coconut shell charcoal, 22.31% was mangrove charcoal, and 61.73% was wood charcoal (Ekawati, 2023). Charcoal contains non-polar carbon compounds, the same as the carbon compounds in asphalt (Mashuri, 2008). Hydrocarbons in asphalt have adhesive properties, which can unite dissimilar particles, like cement (Rohmatun, 2010).

Based on the background explained previously, research will be carried out regarding adding teak wood charcoal as a filler to the AC-WC mixture. This research aims to determine the effect of teak wood charcoal as a filler with various variations as a filler in the Asphalt Concrete-Wearing Course (AC-WC) mixture on the Marshall test, which is by the General Specifications of Bina Marga 2018 2$^{nd}$ Revision. So, this research is expected to be able to make charcoal teak wood as an alternative filler in AC-WC asphalt concrete mixtures by the General Specifications of Bina Marga 2018 2$^{nd}$ Revision.

## 2 Literature Review

### 2.1 Asphalt Concrete Layer

Asphalt concrete layer is a road pavement component consisting of asphalt and a blend of graded aggregates mixed, then spread under hot conditions and compacted at a specified temperature (Saodang, 2005). Asphalt, which functions as a binder in the asphalt concrete mixture, has small voids, so the asphalt concrete layer has high stiffness and stability. Asphalt concrete layers consist of several types of layers, including:

1. AC-WC

   The layer that acts as a wear layer and is flexible and is located at the top of the road pavement layer, which has a minimum thickness of 4 cm (Zahara & Sholichin, 2023).

Received 20 June 2024 , Revised 12 August 2024, Accepted for publication 31 October 2024

2. AC-BC

   The asphalt concrete layer acts as an intermediate layer between the AC-Base and AC-WC layers with a minimum thickness of 6 cm.
3. AC-Base

   The asphalt concrete layer, which acts as a foundation for the pavement layer, is located below the AC-BC layer with a minimum thickness of 7,5 cm.

## 2.2 Plan Asphalt Content

The planned asphalt content is the amount of asphalt used as the basis for making test object samples to determine the optimum asphalt content through testing in the laboratory. According to the SE Minister of PUPR Number 14/SE/M/2019 concerning the design and implementation of continuously graded hot asphalt mixes. In determining the planned asphalt content, the approach method that can be used is the Asphalt Institute method (Kementerian PUPR, 2019).

The design asphalt content can be calculated in the following equation:

$$P = (0{,}035 \times A) + (0{,}045 \times B) + (K \times C) + F \quad (1)$$

P = Percentage of plan (ideal) asphalt content to mixture weight (%)

A = Percentage of aggregate retained on No.8 sieve (%)

B = The percentage of aggregate that passes sieve No. 8 and is retained by sieve No. 200 (%)

C = Percentage of aggregate passing sieve No.200 (%)

K = 0,15 if what passes sieve No.200 is between 11-15%

= 0,18 if what passes sieve No.200 is between 6-10%

= 0,2 if it passes sieve No. 200 ≤5%

F = 0-2% based on aggregate absorption value

(If not available, it is recommended to use 0,7%)

## 2.3 Filler

A filler is a material used to fill voids in the asphalt mixture. The filler added to the asphalt mixture must be dry and free from lumps. In addition, the filler must contain materials that pass the No. Sieve. 200. The filler percentage for cement in the asphalt mixture must range between 1% to 2% of the total aggregate weight, while the filler percentage for others must range between 1% to 3% of the total aggregate weight (Direktorat Jenderal Bina Marga, 2018).

## 2.4 Teak Wood Charcoal

Teak trees are a type of tree that has high-quality wood. Therefore, teak wood is often used as a raw material in the furniture manufacturing industry. Teak wood production is less than wood in

Received 20 June 2024 , Revised 12 August 2024, Accepted for publication 31 October 2024
 p-ISSN: 2963-7244 e-ISSN: 2964-6960 , DOI: https://doi.org/10.56444/jcets.v3i2

general, so teak wood waste must be utilized optimally. One use of teak wood waste obtained from the remains of furniture entrepreneurs can be used as a material for making charcoal.

Charcoal is produced from burning wood at high temperatures, so most of its chemical components are carbon (Salim, 2016). Charcoal contains non-polar carbon compounds, the same as the carbon compounds in asphalt (Mashuri, 2008). Hydrocarbons in asphalt have adhesive properties, which can unite dissimilar particles, like cement (Rohmatun, 2010).

## 2.5 Marshall Test

The Marshall test aims to determine the physical properties of the asphalt mixture, such as the level of stiffness and flexibility. General Specifications of Bina Marga 2018 2nd Revision have stipulated provisions for the Marshall Mix Laston (AC-WC) parameters, which are shown as follows:

**Table 1.** Conditions for Marshall Parameters for AC-WC Mixture

| Marshall Parameters | Specification Requirements |
|---|---|
| Stability | Min. 800 kg |
| Flow | 2-4 mm |
| Marshall Quotient | Min. 250 kg/mm |
| VIM | 3-5 % |
| VMA | Min. 15% |
| VFA | Min. 65% |

Source: General Specifications of Bina Marga 2018 2nd Revision

### 2.5.1 Stability

Several factors, including the surface roughness, grain shape, aggregate gradation, mixture density, and asphalt adhesion, influence the stability value. A high stability value indicates that the road pavement has a high level of stiffness. However, suppose the stability value is too low. In that case, it will cause the road pavement to have a high level of flexibility so that it will easily experience deformation when subjected to traffic loads (Saodang, 2005).

### 2.5.2 Flow

A flow value that is too high will cause the road pavement to have high flexibility so that the road pavement will easily experience deformation when subjected to traffic loads. On the other hand, if the flow value is too low, it will cause the road pavement to have high stiffness, so the road pavement will easily crack when subjected to traffic loads (Febrianto et al., 2014).

### 2.5.3 Marshall Quotient

The Marshall Quotient is an indicator that shows the level of stiffness or flexibility in road pavement. The large or small level of the flow value influences the Marshall Quotient value. A high

Received 20 June 2024 , Revised 12 August 2024, Accepted for publication 31 October 2024

Marshall Quotient value indicates that the road pavement has a high level of stiffness. However, suppose the Marshall Quotient value is too low. In that case, it will cause the road pavement to have high flexibility and easily experience deformation when subjected to traffic loads.

### 2.5.4 VIM

VIM or voids in the mixture is the percentage of air voids in the solid asphalt and affects the durability of the road pavement. A VIM value that is too high will cause the road pavement to have significant air cavities so that the road pavement will quickly oxidize, which will reduce the adhesion of the asphalt and aggregate. This condition causes the road pavement to experience ravelling. On the other hand, when the VIM value is too low, it will cause the road pavement to have small air cavities so that when the road pavement is subjected to traffic loads, experiences an increase in layer density and is exposed to high temperatures, the asphalt will melt and come out onto the road surface. This condition causes the road pavement to bleed (Waani, 2013).

### 2.5.5 VMA

VMA or voids between aggregates are the percentage of voids between aggregate grains in road pavement, including air voids and effective asphalt and influence the durability of the road pavement. The VMA value is influenced by aggregate gradation and the percentage of asphalt content. When the VMA value (air voids are smaller than the voids filled with asphalt) can cause the road pavement, when it is subjected to traffic loads, experience an increase in layer density and is exposed to high temperatures, the asphalt will melt and come out onto the road surface. This condition causes the road pavement to bleed. However, if the VMA value (air voids are greater than the voids filled with asphalt), it can cause the road pavement to oxidize quickly, which reduces the adhesion of the asphalt and aggregate. This condition causes the road pavement to experience ravelling.

### 2.5.6 VFA

VFA or voids filled with asphalt is the percentage of voids that can be filled with asphalt in a solid asphalt and affects the durability of the road pavement. The VFA value indicates the water and air tightness of the road pavement. However, when the VFA value is too high, it will cause the road pavement to have large voids filled with asphalt, so that when the road pavement is subjected to traffic loads, experiences an increase in layer density and is exposed to high temperatures, the asphalt will melt and come out onto the road surface. This condition causes the road pavement to bleed. On the other hand, a VFA value that is too low will cause the road pavement to have small voids filled with asphalt so that the road pavement will quickly oxidize, which will reduce the adhesion of the asphalt and aggregate. This condition causes the road pavement to experience ravelling.

Received 20 June 2024 , Revised 12 August 2024, Accepted for publication 31 October 2024

## 3 Research Methods

This research was carried out in a road materials laboratory. The weight of one test object made is ±1200 grams. The weight of each material used, including aggregate, asphalt and teak charcoal, was increased by 10% of the original weight during the research process. Thus, the total weight of the resulting test object is ±1320 grams. The asphalt used in this research is Pertamina Penetration 60/70 Asphalt, and the filler used is teak wood charcoal with varying filler levels of 0%, 1%, 2%, 3% and 4%. The stages carried out in this research are stated as follows:

1. Material test
2. Calculation of planned asphalt content
3. Making test objects with planned asphalt content p-1%, p, and p+1%
4. Marshall test to find the optimum asphalt content value
5. Making test objects with the addition of teak charcoal filler variations of 0%, 1%, 2%, 3% and 4%
6. Marshall test to find the optimum filler content value
7. Research result
8. Conclusion

## 4 Result and Discusiion

### 4.1 Determination of Planned Asphalt Content

$$P = (0{,}035 \times A) + (0{,}045 \times B) + (K \times C) + F$$
$$= (0{,}035 \times 57) + (0{,}045 \times 36{,}5) + (0{,}18 \times 6{,}5) + 1{,}71$$
$$= 6{,}52\%$$

Based on the planned asphalt content calculation results, this study used variations in the scheduled asphalt content of P-1%, P, and P+1%. The results of variations in planned asphalt content are shown as follows:

**Table 2.** Result of Planned Asphalt Content Variatons

| Plan Asphalt Content | Variations in Asphalt Content | Number of Test Objects |
|---|---|---|
| P-1 | 5,52% | 5 |
| P | 6,52% | 5 |
| P+1 | 7,52% | 5 |

Source: Research Result

### 4.2 Determination of Optimum Asphalt Content

The results of determining the optimum asphalt content were obtained through Marshall testing on various variations of asphalt content, namely 5.52%, 6.52% and 7.52%. The recapitulation of Marshall parameters can be shown as follows:

Received 20 June 2024 , Revised 12 August 2024, Accepted for publication 31 October 2024

**Table 3.** The Recapitulation of Marshall Parameter

| Marshall Parameters | Specification Requirements | Variations in Asphalt Content | | |
|---|---|---|---|---|
| | | **5,52%** | **6,52%** | **7,52%** |
| Stability | Min. 800 kg | 2437,66 | 2355,32 | 1875,12 |
| Flow | 2-4 mm | 2,58 | 2,77 | 3,15 |
| Marshall Quotient | Min. 250 kg/mm | 943,92 | 851,42 | 596,39 |
| VIM | 3-5% | 6,47 | 3,57 | 1,71 |
| VMA | Min. 15% | 16,28 | 15,59 | 15,82 |
| VFA | Min. 65% | 60,28 | 77,10 | 89,17 |

Source: Research Result

It is done to find the optimum asphalt content value by determining the middle value of the Marshall parameter that meets it. The graph for determining the optimum asphalt content value is shown as follows:

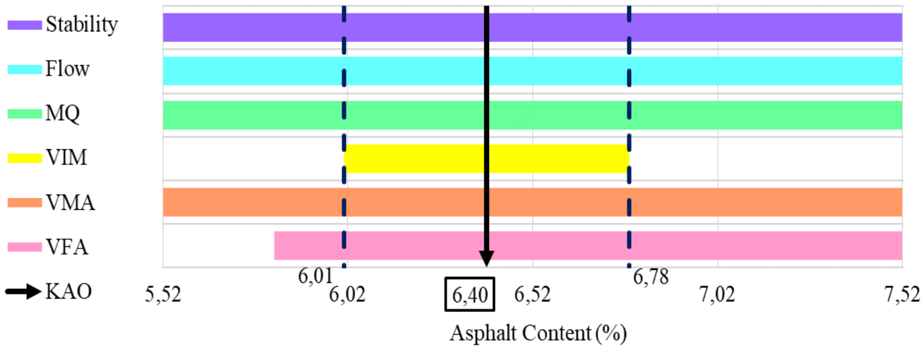



**Figure 1.** Graph of Optimum Asphalt Content
Source: Research Result

## 4.3 Determination of Optimum Filler Content

The results of determining the optimum filler content were obtained through Marshall testing on various variations of filler content in the form of teak wood charcoal at 0%, 1%, 2%, 3% and 4%. The recapitulation of Marshall parameters can be shown as follows:

**Table 4.** The Recapitulation of Marshall Parameter

| Marshall Parameters | Specification Requirements | Variations in Filler Content | | | | |
|---|---|---|---|---|---|---|
| | | **0%** | **1%** | **2%** | **3%** | **4%** |
| Stability | Min. 800 kg | 2361,03 | 2601,33 | 2672,05 | 2580,69 | 2299,03 |
| Flow | 2-4 mm | 2,73 | 2,40 | 2,25 | 2,40 | 2,75 |
| Marshall Quotient | Min. 250 kg/mm | 867,21 | 1084,48 | 1188,28 | 1076,06 | 835,28 |
| VIM | 3-5% | 3,92 | 4,77 | 6,64 | 9,53 | 9,59 |

Received 20 June 2024 , Revised 12 August 2024, Accepted for publication 31 October 2024
 p-ISSN: 2963-7244 e-ISSN: 2964-6960 , DOI: https://doi.org/10.56444/jcets.v3i2

| | | | | | | |
|---|---|---|---|---|---|---|
| VMA | Min. 15% | 15,67 | 16,42 | 18,06 | 20,60 | 20,65 |
| VFA | Min. 65% | 75,01 | 70,94 | 63,23 | 53,72 | 53,55 |

Source: Research Result

### 4.3.1 Stability

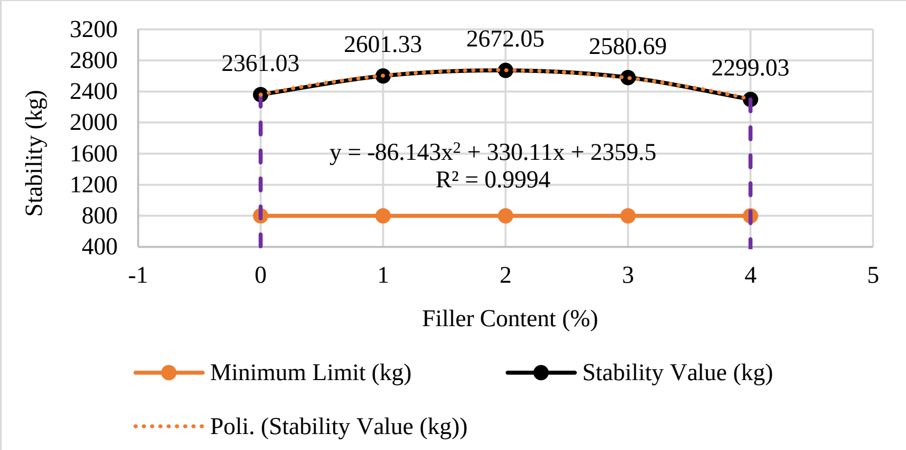



**Figure 2.** Graph of Recapitulation of Stability Value Results
Source: Research Result

Stability values that meet the General Specifications of Bina Marga 2018 2nd Revision are found in all variations of filler content, where the minimum stability value is 800 kg. The test results show that at filler levels between 0% and 2%, there is an increase in the stability value, so the road pavement has an increased level of stiffness. Meanwhile, at filler levels between 2% and 4%, there is a decrease in the stability value, so the road pavement has a reduced stiffness level.

### 4.3.2 Flow

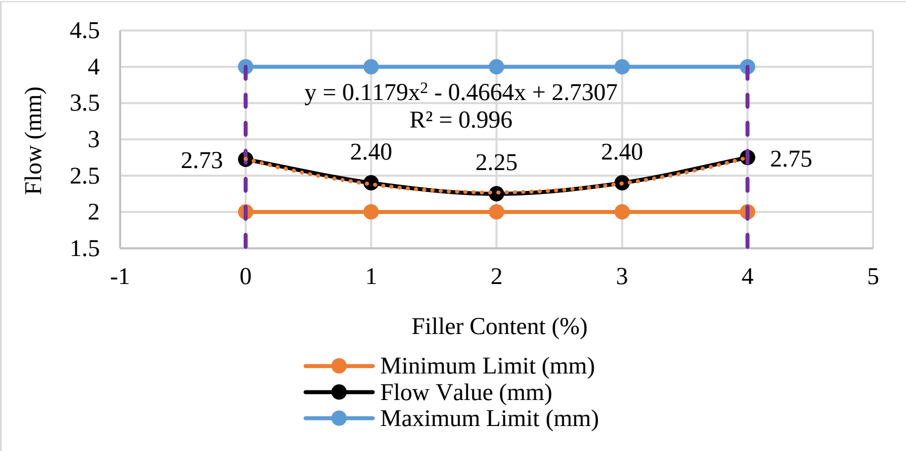



**Figure 3.** Graph of Recapitulation of Flow Value Results
Source: Research Result

Received 20 June 2024 , Revised 12 August 2024, Accepted for publication 31 October 2024

Flow values that meet the General Specifications of Bina Marga 2018 2nd Revision are found in all variations of filler content, where the flow value is set between 2 mm and 4 mm. The test results show that at filler levels between 0% and 2%, there is a decrease in the flow value, so the road pavement has an increased level of stiffness. Meanwhile, at filler levels between 2% and 4%, there is an increase in the flow value so the road pavement has a reduced level of stiffness.

### 4.3.3 Marshall Quotient

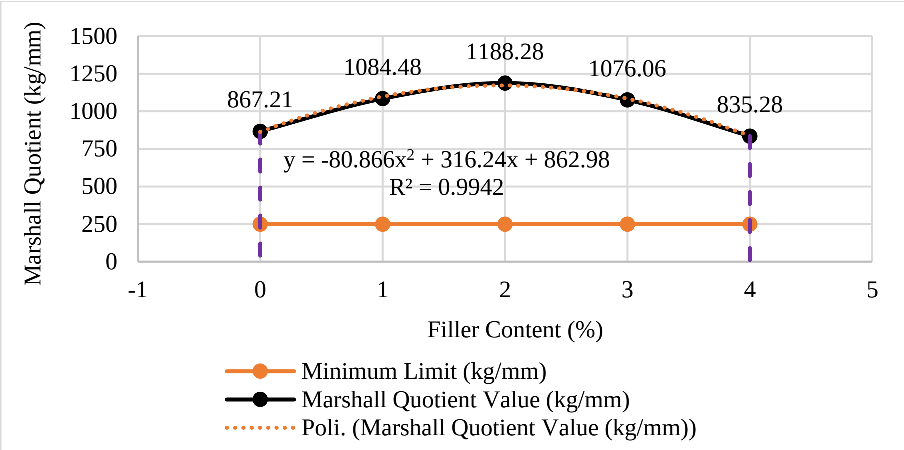



**Figure 4.** Graph of Recapitulation of Marshall Quotient Value Results
Source: Research Result

Marshall Quotient values that meet the General Specifications of Bina Marga 2018 2nd Revision are found in all variations of filler content, where the minimum Marshall Quotient value is 250 kg/mm. The test results show that at filler levels between 0% and 2%, there is an increase in the Marshall Quotient value, so the asphalt mixture has an increased level of stiffness. Meanwhile, at filler levels between 2% and 4%, there is a decrease in the Marshall Quotient value, so the road pavement has a reduced stiffness level.

### 4.3.4 Voids in Mix (VIM)

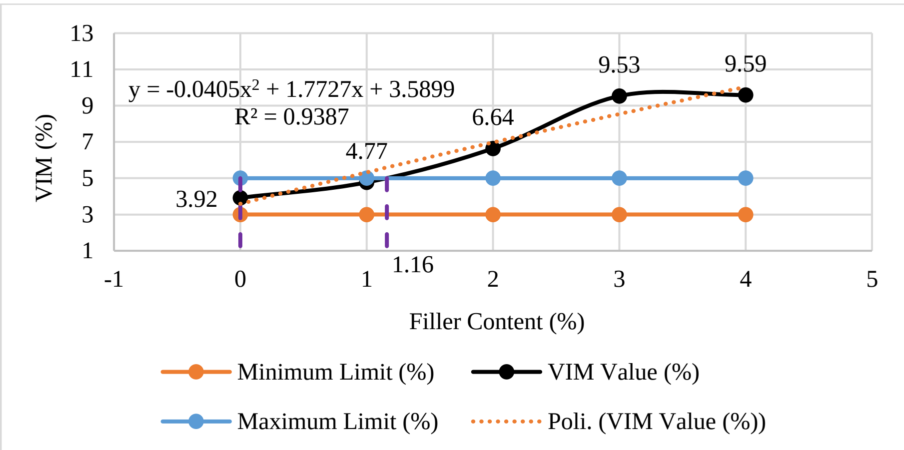



**Figure 5.** Graph of Recapitulation of VIM Value Results
Source: Research Result

Received 20 June 2024 , Revised 12 August 2024, Accepted for publication 31 October 2024

The VIM value that meet the General Specifications of Bina Marga 2018 2nd Revision is found in filler content variations of 0% and 1%, where the VIM value is set between 3% and 5%. The test results show that each filler content increases, so the asphalt mixture has large air cavities.

### 4.3.5 Voids in Mineral Aggregate (VMA)

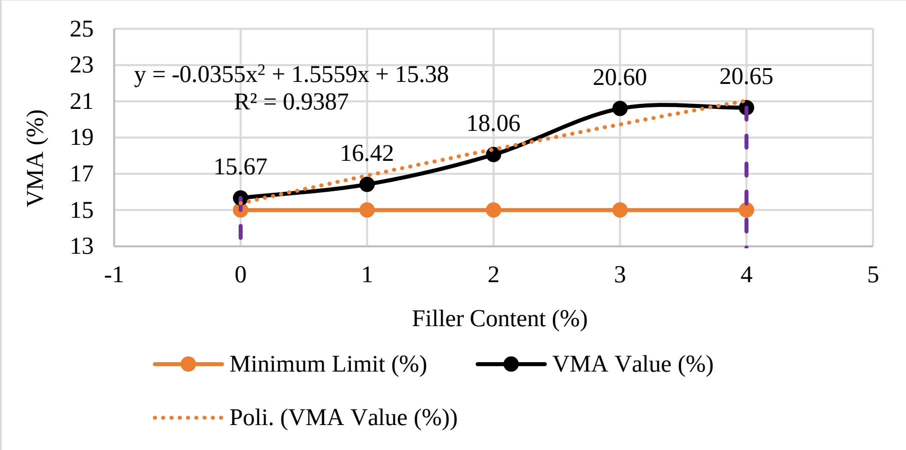



**Figure 6.** Graph of Recapitulation of VMA Value Results
Source: Research Result

The VMA value that meet the General Specifications of Bina Marga 2018 2nd Revision is found in all variations of filler content, where the minimum VMA value is 15%. The test results show an increase in each filler content, so the asphalt mixture has larger air cavities between aggregates and smaller cavities between aggregates filled with asphalt.

### 4.3.6 Voids Filled with Asphalt (VFA)

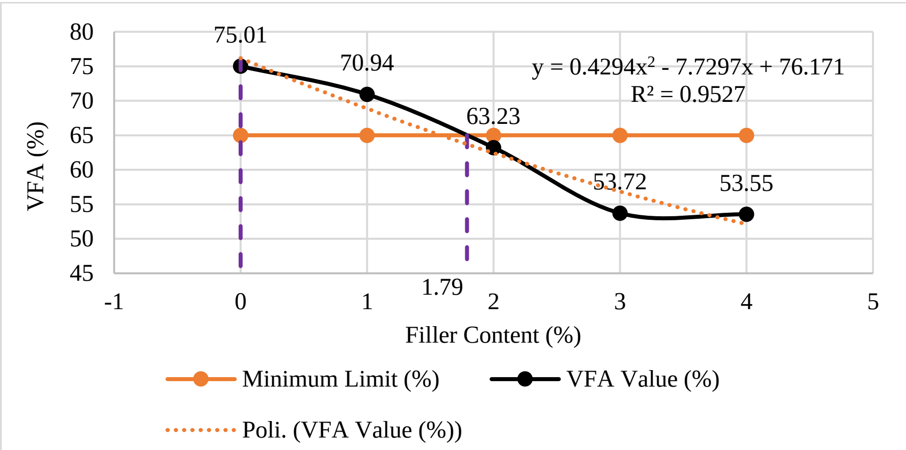



**Figure 7.** Graph of Recapitulation of VFA Value Results
Source: Research Result

The VFA value that meet the General Specifications of Bina Marga 2018 Revision 2 is found in filler content variations of 0% and 1%, where the minimum VFA value is 65%. The test results show a decrease in each filler content, so the asphalt mixture has small voids filled with asphalt.

Received 20 June 2024 , Revised 12 August 2024, Accepted for publication 31 October 2024

### 4.3.7 Optimum Filler Content

It is done to find the optimum filler content value by determining the middle value of the Marshall parameter that meets it. The graph for determining the optimum asphalt content value is shown as follows:

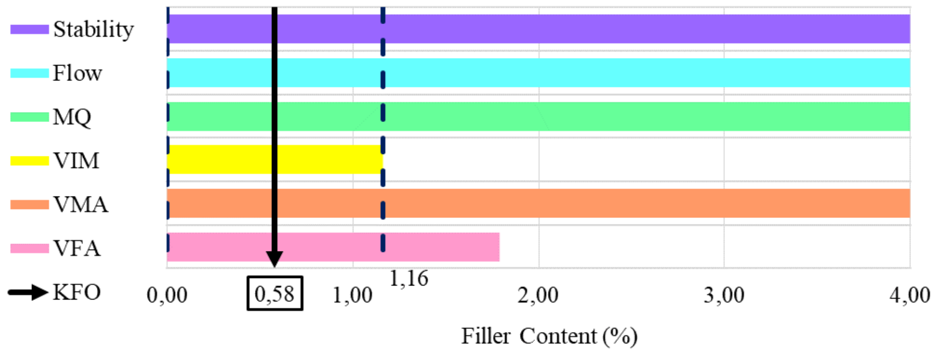



**Figure 8.** Graph of Optimum Filler Content
Source: Research Result

## 4.4 Effect of Adding Teak Charcoal Filler

The effect of adding teak wood charcoal as a filler was obtained by comparing each Marshall parameter between the asphalt filler mixture, namely at a filler content of 0% and the asphalt mixture using filler, namely at a filler content of 0.58%. Marshall parameter results without filler were calculated to determine the optimum filler content, a percentage of 0%. Meanwhile, the Marshall parameter results using a filler of 0.58% were obtained through a polynomial equation from the graphical results of each Marshall parameter in determining filler content. The Marshall parameter comparison results are shown as follows:

**Table 5.** Marshall Parameter Comparison Results

| Marshall Parameters | Specification Requirements | Unit | Filler Content | | Percentage | Information |
|---|---|---|---|---|---|---|
| | | | 0% | 0,58% | | |
| Stability | Min. 800 kg | kg | 2361,03 | 2521,99 | 6,82 | Increase |
| Flow | 2-4 mm | mm | 2,73 | 2,50 | -8,26 | Decrease |
| Marshall Quotient | Min. 250 kg/mm | kg/mm | 867,21 | 1019,20 | 17,53 | Increase |
| VIM | 3-5% | % | 3,92 | 4,60 | 17,46 | Increase |
| VMA | Min. 15% | % | 15,67 | 16,27 | 3,83 | Increase |
| VFA | Min. 65% | % | 75,01 | 71,83 | -4,23 | Decrease |

Source: Research Result

Based on Table 5 regarding the results of Marshall parameter comparisons, an increase in the stability value of 6,82%, a decrease in the flow value of 8,26%, an increase in the Marshall Quotient value of 17,53%, an increase in the VIM value of 17.46%, an increase in the VMA value were obtained of 3,83%, and a decrease in VFA value of 4,23%. These results show that teak charcoal as a filler can provide strong adhesion between particles in road pavement, thereby increasing the strength of the road

Received 20 June 2024 , Revised 12 August 2024, Accepted for publication 31 October 2024

pavement. However, using teak wood charcoal as a filler can increase air voids in the road pavement because the asphalt tends to be absorbed more by the teak wood charcoal. As a result, asphalt and filler cannot fill the air spaces in the road pavement optimally, this can cause the road pavement to become porous, if the use of filler exceeds the specified limits.

## 5 Conclusion

Based on the results of research that has been carried out regarding the effect of adding teak charcoal as a filler on the performance of the Asphalt Concrete-Wearing Course (AC-WC) mixture, can be concluded as follows:

1. From the results of Marshall characteristic testing using asphalt content of 5,52%, 6,52% and 7,52%, the optimum asphalt content value was obtained, namely 6,40%. The Marshall characteristic test results for the optimum asphalt content value have meet the General Specifications of Bina Marga 2018 2nd Revision, where the stability value was 2361,03 kg, the flow value was 2,73 mm, the Marshall Quotient value was 867,21 kg/ mm, VIM value 3,92%, VMA value 15,67%, and VFA value 75,01%.
2. From the results of testing Marshall characteristics using variations in filler content in the form of teak wood charcoal at 0%, 1%, 2%, 3% and 4%, the optimum filler content value was obtained at 0,58%. The calculation results using a polynomial equation for the optimum filler content value have meet the General Specifications of Bina Marga 2018 2nd Revision, where a stability value was 2521,99 kg, the flow value was 2,50 mm, the Marshall Quotient value was 1019,20 kg/mm, the VIM value was 4,60%, the VMA value was 16,27%, and the VFA value was 71,83%.
3. From the results of the comparison of each Marshall parameter between asphalt mixtures without using filler, namely at a filler content of 0% and asphalt mixtures that use filler, namely at a filler content of 0,58%, an increase in stability value of 6,82% was obtained, a decrease in flow value of 8,26%, an increase in the Marshall Quotient value of 17,53%, an increase in the VIM value of 17,46%, an increase in the VMA value of 3,83%, and a decrease in the VFA value of 4,23%.
4. This research shows that teak charcoal as a filler can provide strong adhesion between particles in road pavement, thereby increasing the strength of road pavement. However, using teak wood charcoal as a filler can increase air voids in the road pavement because the asphalt tends to be absorbed more by the teak wood charcoal. As a result, asphalt and filler cannot fill the air spaces in the road pavement optimally, this can cause the road pavement to become porous, if the use of filler exceeds the specified limits.

Received 20 June 2024 , Revised 12 August 2024, Accepted for publication 31 October 2024

## 6 Reference

Badan Pusat Statistik. (2023). *Produksi Perusahaan Pembudidaya Tanaman Kehutanan Menurut Jenis Produksi, 2020-2022*.

Direktorat Jenderal Bina Marga. (2018). *Spesifikasi Umum Tahun 2018 Untuk Pekerjaan Jalan dan Jembatan (Revisi 2)*. Kementerian PUPR.

Ekawati, C. J. K. (2023). *Alternatif Bahan Baku Arang Aktif* (1st ed.). Penerbit Rena Cipta Mandiri.

Febrianto, N., Setyawan, A., & Sarwono, D. (2014). Sifat-Sifat Marshall Pada Lapis Tipis Campuran Aspal Panas Dengan Penambahan Crumb Rubber. *E-Jurnal Matriks Teknik Sipil*, 748–758.

Kementerian PUPR. (2019). *Perancangan dan Pelaksanaan Campuran Beraspal Panas Bergradasi Menerus (Laston) Menggunakan Slag*.

Mashuri. (2008). Sifat-Sifat Mekanis Aspal Yang Ditambahkan Serbuk Arang Tempurung Kelapa. *Majalah Ilmiah Mektek*, *VIII*(1), 42–48.

Rohmatun, Y. (2010). *Sistem Koloid dan Senyawa Hidrokarbon* (U. Widuri & D. S. Rahayu, Eds.; 1st ed.). ALPRIN.

Rumbyarso, Y. P. A. (2022). *Infrastruktur Pembaharu (Silica Fume in Asphalt Concrete-Wearing Course)* (1st ed.). CV. Amerta Media.

Salim, R. (2016). *Karakteristik dan Mutu Arang Kayu Jati (Tectona grandis) dengan Sistem Pengarangan Campuran pada Metode Tungku Drum The Quality and Characteristics of Teak (Tectona grandis) Charcoal Made by Mixed Carbonisation in Drum Kiln*. 53–64.

Saodang, H. (2005). *Buku 2 Perancangan Perkerasan Jalan Raya* (1st ed.). Nova.

Utomo, N., Wahjudijanto, I., & Yasin, F. S. R. (2020). Penggunaan Limbah Serbuk Besi Sebagai Material Pengisi (Filler) Pada Campuran Struktur Perkerasan Jalan Kolektor Ponco–Jatirogo (Sta.130+200–Sta.138+700). *Jurnal Envirotek*, *12*(2), 64–74.

Waani, J. E. (2013). Evaluasi Volumetrik Marshall Campuran AC-BC (Studi Kasus Material Agregat di Manado dan Minahasa). *Jurnal Teoretis Dan Terapan Bidang Rekayasa Teknik Sipil*, *20*(1), 67–77.

Zahara, N. A., & Sholichin, I. (2023). Pengaruh Variasi Suhu Pada Campuran Aspal AC-WC Terhadap Karakteristik Marshall. *Rekayasa Jurnal Teknik Sipil Universitas Madura*, *8*(1), 23–28.

Received 20 June 2024 , Revised 12 August 2024, Accepted for publication 31 October 2024