Mechanical Characteristics of the Asphaltic Concrete Mixture with the Addition of Steel Fibers

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Abstract. Roads have the strength and durability to be able to handle the existing traffic load for their planned lifespans, and damage must be minimized. Methods of minimizing damage include self-healing. Before testing self-healing ability, steel fibers that have a solid density and as a good conductor must be tested for their mechanical characteristics in the AC-WC mixture. These consist of the Marshall characteristic tests and the volumetric characteristic test. With an asphalt content of 5.7%, the 0.25%, 0.5%, 0.75%, and 1% addition of steel fibers into the asphalt-concrete wearing-course (AC-WC) mixture increases the value of Void Filled with Asphalt (VFA), stability, and the Marshall Quotient and reduces the value of Void in The Compacted Mixture (VITM), Void in Mineral Aggregate (VMA), and flow. However the VITM value obtained is below the 3% requirement, because the number of cavities in the mixture is already close to the minimum requirement without the addition of steel fibers. Another reason is the high 5.7% asphalt content. The optimum steel fiber content, obtained using the narrow range method, is 0.625%. Based on its mechanical characteristics, steel fiber is a recommended additive.

1. Introduction
The layer of flexible pavement has a planned lifespan, which is the maximum service life of the road, but sometimes this does not go according to plan. This is the result of many factors. The factors that cause damage to road pavement construction include poor drainage systems, climate, and unstable soil conditions and are interrelated. [1]

Considering the high cost factor and environmental conditions, a road pavement method that can overcome these problems is needed. An ideal method is able to minimize damage to layers of the pavement so that the road lasts the planned lifespan. One of these methods is self-healing. This method requires the latest equipment and research to determine the strength of the mixtures. Previous research on this method only relates to ideal materials and additives, so this method is not widely used in Indonesia. The research tests the mechanical characteristics of the additives because the mechanical characteristics of the mixture are the requirement that the mixture can be used for road pavement construction in accordance with the terms and conditions that applied in Indonesia.

This research is based on the background of the problem. It is a continuation of previous research in which steel fibers, which are good conductors (of heat) and made of steel wool, are used as additives to improve the mechanical characteristics of pavement in asphalt-concrete wearing-course (AC-WC). So in this study will investigate how the effect of the addition of steel fibers as an additive in asphalt mixture.
The purpose of this study is to analyze how a 0%, 0.25%, 0.5%, 0.75%, and 1% addition of steel fibers effects asphalt regarding the stability and durability of the mixture as well as the mixed volumetric characteristics.

2. Methods

2.1. Sample Preparation
Sample preparation consisted of several tests, namely aggregate quality testing (Los Angeles, rough and fine specific gravity, crushing, and impact), filler testing, and asphalt quality testing (specific gravity, viscosity, ductility, flash point, burn point, penetration, and softening points).

2.2. Sample Design
The sample design consists of the gradation design and the composition of the control mix aggregate, as can be seen in Table 3. The variation of steel fibers used (0.25%, 0.5%, 0.75%, and 1%) can be seen in Figure 1. The number of samples used is 15, namely for standard immersion at each percent of steel fiber content.

### Table 3. Design of Gradation and Composition Aggregate To Mix

| Materials       | Sieve  | Qualified Specifications (%) | Restained Sieve (%) | Amount According to Specifications Strained (%) | Amount (gram) |
|-----------------|--------|------------------------------|---------------------|-----------------------------------------------|---------------|
| Coarse aggregate | 19,1   | ¾” | 100 | 100 | 100 | 0 | 0 | 0 |
|                 | 12,7   | ½” | 90 | 100 | 96,5 | 3,5 | 3,5 | 42 |
| (42,22%)        | 9,52   | 8” | 77 | 90 | 83,8 | 16,2 | 12,7 | 153 |
|                 | 4,76   | #4 | 53 | 69 | 57,8 | 42,2 | 26 | 312 |
| Fine Aggregate  | 2,36   | #8 | 33 | 53 | 38,9 | 61,2 | 18,9 | 227 |
|                 | 1,18   | #16 | 21 | 40 | 25,9 | 74,1 | 13 | 156 |
|                 | 0,59   | #30 | 14 | 30 | 19,9 | 80,2 | 6 | 72 |
| (51,67%)        | 0,279  | #50 | 9 | 22 | 14,6 | 85,5 | 5,3 | 64 |
|                 | 0,149  | #100 | 6 | 15 | 9,9 | 90,1 | 4,7 | 56 |
|                 | 0,074  | #200 | 4 | 10 | 6,1 | 93,9 | 3,8 | 45 |
| Filler (6,11 %) | PAN    | 100 | 6,1 | 73 |

**Figure 1. Aggregate Grading Plan**
2.3. Sample Making
Steel fiber is incorporated into the asphalt mixture without changing the aggregate composition or changing the asphalt content. Then, the material is heated for 2 hours and mixed until it reaches the mixing temperature. The cylindrical samples have a diameter of 100 mm and a height of about 75 ml and are compressed 75 times with a Marshall hammer on each side.

2.4. Marshall Testing
The samples were immersed with standard immersion (30 minutes) and loading was carried out at a constant speed of 51 mm (two inches) per minute until failure occurred.

2.5. Methods
Test methods implemented to obtain Marshall characteristics of the AC-WC mixture with the addition of steel fibers refer to the General Specifications of Bina Marga 2018 Division 1. In order to observe the condition of the test sample, a standard immersion was carried out for 30 minutes. The test results were then analyzed and compared to obtain the Marshall characteristics data required for the AC-WC mixtures [2], [3], [4].

3. Result and discussion

3.1. Aggregate Physical Examination Results
The coarse aggregate, fine aggregate, and filler used for the AC-WC mixture originated from Marga Maju Mapan Inc. The results of the aggregates physical properties examination include coarse aggregates, fine aggregates, and fillers as in Table 5. Based on the test results in Table 5, all parameters meet Bina Marga requirements, so the aggregate can be used in an AC-WC mixture.

| No | Type of Testing | Terms           | Result | Unit   | Qualification |
|----|----------------|-----------------|--------|--------|---------------|
| A. Coarse Aggregate |                 |                 |        |        |               |
| 1  | Abrasion with Los Angeles machines | Max 40 | 32.962 | %      | Qualified     |
| 2  | Stickiness to Asphalt             | Min 95 | 98     | %      | Qualified     |
| 3  | Apparent Specific Gravity         | Min 2.5 | 2.69   | g/cm$^3$ | Qualified     |
| 4  | Absorption                        | Max 3  | 0.55   | %      | Qualified     |
| B. Fine Aggregate |                 |                 |        |        |               |
| 1  | Absorption                        | Max 3  | 2.88   | %      | Qualified     |
| 2  | Apparent Specific Gravity         | Min 2.5 | 2.72   | g/cm$^3$ | Qualified     |
| C. Filler |                 |                 |        |        |               |
| 1  | Apparent Specific Gravity         | Min 2.5 | 2.5    | g/cm$^3$ | Qualified     |

3.2. Asphalt Physical Examination Results
The physical examination of the asphalt was carried out using Asphalt Shell with 60/70 penetration available at Marga Maju Mapan Inc.’s laboratory; the results can be seen in Table 6. Based on these results, it can be concluded that all parameters meet Bina Marga’s requirements, so the asphalt can be used in an AC-WC mixture.
### Table 6. Asphalt Physical Examination Results

| No. | Type of Testing               | Specification | Result |
|-----|-------------------------------|---------------|--------|
| 1   | Penetration at 25°C (dmm)     | 60-70         | 68     |
| 2   | Softening Point (°C)          | ≥ 48          | 52     |
| 3   | Ductility at 25°C (cm)        | ≥100          | 111.2  |
| 4   | Flash Point (°C)              | ≥232          | 323    |
| 5   | Specific Gravity (gram/cc)    | ≥1.0          | 1.036  |

#### 3.3. Steel Fiber Inspection Results

The steel’s specific gravity is 7.8 g/cm³. After testing for specific gravity, the steel fibers are sieved. Then the steel fibers that pass the filter No. 16 (1.18 mm) were taken.

Steel fibers were used as additives comprising 0.25%, 0.5%, 0.75%, or 1% of the total weight of the aggregate. The respective weights of the fibers were 3 g, 6 g, 9 g, and 12 g.

#### 3.4. Analysis of the Effect of Addition of Steel Fiber to Marshall Characteristics

Marshall characteristic values for each amount of steel fiber content increased and decreased, which can be seen in Figure 3 to Figure 8 [5], [6], [7].

![Figure 3. Steel Fiber and VFA](image3.png)

![Figure 4. Steel Fiber and Stability](image4.png)

![Figure 5. Steel Fiber and VITM](image5.png)

![Figure 6. Steel Fiber and MQ](image6.png)
Figure 3 shows that the VFA values obtained in this study are relatively high and meet the specifications. This is because steel fibers do not have air cavities, so asphalt can fill cavities between aggregates and coat aggregates quickly. In addition, because steel fibers do not soften and harden when heated, the asphalt will not glue the fibers together. Therefore, there is no clumping that would prevent the asphalt from filling the entire cavity of the AC-WC mixture.

In Figure 4, the stability of the mixture increases. This is caused by the asphalt’s function as an adhesive. However, even though the asphalt content is quite high, it did not reduce density or enlarge cavities in the mixture. This shows that stability is above the minimum requirement because steel fibers can improve the interlocking of aggregates or asphalt coatings on aggregates. This result is also in accordance with the obtained Void in Mineral Aggregate (VMA) value.

In Figure 5 which shows the graph is relatively down, it can be seen that the asphalt content with the addition of steel fibers reduces the VITM value because the aggregate gradation in the mixture is a solid gradation. In addition, as the asphalt content is relatively high, the addition of steel fibers significantly reduces Void in The Compacted Mixture (VITM). The VITM values on the graph, all of which are below the minimum limit, indicate that without the addition of steel fibers, cavity content may be near the minimum.

In Figure 6, it can be seen that Marshall Quotient is rising and that it meets the existing specifications. This is because the mixture is quite stable. MQ tends to rise to a certain value with an increase in steel fiber content.

In Figure 7, the graph of Void in Mineral Aggregate (VMA) is relatively down. This is due to the nature of steel fibers; they are dense, do not melt when heated, and their shape does not interfere with the viscosity between aggregates. The small VMA value is also caused by the influence of the air cavity, as it is greater than the asphalt cavity; therefore, it has a more significant effect on the viscosity between the aggregates.

In Figure 8, the graph of flow values tends to decrease due to the fact that steel fibers are more rigid than asphalt. Consequently, the addition of steel fibers results in increased stiffness and reduced flexibility of the mixture, so the addition of steel fibers improves the basic properties.

3.5. Determination of Optimum Steel Fiber Content Using the Narrow Range Method
The narrow range method is carried out by plotting the amounts of steel fibers in an AC-WC mixture on each of the Marshall characteristics that have been obtained on the volumetric curve. The optimum steel fiber content of the selected AC-WC mixture is the steel fiber content range (midrange) at a mixture density that meets all volumetric components (VMA, VITM, and VFA) and Marshall parameters (stability, flow, and MQ). Figure 9 shows that from the area of characteristic values that have fulfilled the 2018 Bina Marga requirements, the optimum steel fiber content can be determined.
In this narrow range method, the VITM value is ignored because the VITM value is below the minimum requirement. So, we can assume that this method does not take air cavity into account. It can be seen in Figure 9 that the optimum steel fiber content obtained using the narrow range method, which is determined from the volumetric characteristic values and Marshall parameters, is 0.625%.

4. Conclusions
Based on this research of the mechanical characteristics of the Asphaltic Concrete mixture, it can be concluded that steel fiber is a good additive. With this additive, almost all of the mechanical and volumetric characteristics of the mixture meet the requirements. In terms of maintaining pavement, steel fibers can save costs by reducing the severity of damage. Steel fiber is also a material that is difficult for the environment to decompose, so the use of steel fibers in this study can reduce the amount of steel waste.

References
[1] I Made Udiana, Andre R. Saudale and Jusuf J. S. Pah 2014 Analisa Faktor Penyebab Kerusakan Jalan (Studi Kasus Ruas Jalan W. J. Lalamentik dan Ruas Jalan GOR Flobamora) vol III no 1 (Kupang: Jurnal Teknik Sipil Undana Kupang) p 17
[2] Suprapto 2004 Bahan dan Struktur Jalan Raya Edisi II (Yogyakarta: Biro Penerbit KMTS FT UGM)
[3] Direktorat Jenderal Bina Marga 2018 Spesifikasi Umum Divisi I Pekerjaan Konstruksi Jalan dan Jembatan (Yogyakarta: Kementrian Pekerjaan Umum)
[4] Rian Putrowijoyo 2006 Kajian Laboratorium Sifat Marshall dan Durabilitas Asphalt Concrecte - Wearing Coarse (AC-WC) dengan Membandingkan Penggunaan Antara Semen Portland dan Abu Batu Sebagai Filler (Semarang: Tesis Program Magister Teknik Sipil Universitas Diponegoro)
[5] Wahjoedi 2009 Karakteristik Marshall dan Indeks Kekuatan Sisa (IKS) pada Campuran Butonite Mastic Asphalt (BMA) (Semarang: Politeknik Negri Semarang)
[6] Hary Christady Hardiyatmo 2007 Pemeliharaan Jalan Raya (Yogyakarta: Gajah Mada University Press)
[7] John Read and David Whiteoak 2003 The Shell Bitumen Handbook, ed Robert N. Hunter (UK: Thomas Telford)