Utilization of Bamboo Fiber towards sustainable asphalt mixture

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Abstract. Stone Mastic Asphalt (SMA) is a gap-graded asphalt mixture that depends on the stone-to-stone contact to provide its load-carrying capacity against rutting and stripping. Even though SMA has good performance, especially in resisting permanent deformation, it suffers from excessive binder drain down due to high bitumen content. Thus, the aim of this study is intended to utilize bamboo fiber to control the drainage and bleeding problem. In this study, bamboo fiber is chosen as a modified binder to enhance the performance of stone mastic (SMA 20) due to more economical than other conventional fibers. The aim of this study to evaluate the mechanical performance of bamboo fiber stone mastic asphalt (SMA) in terms of Marshall stability, resilient modulus, dynamic creep, and Cantabro Loss. Twelve samples of SMA 20 mix with PEN 60/70 binders are tested for each test. Bamboo fiber in the range of 0%, 0.2%, 0.3%, 0.4%, 0.5% and 0.6% of on the aggregate weight used in the original mix design. From the results, it shows that the addition of 0.4% fiber contributes to the lowest value of abrasion and dynamic creep and 0.4% producing the highest value for resilient modulus, stability, density, and stiffness. Based on that, 0.4 % is the optimum fiber content that could be used to design. Thus, it can be concluded that the existence of fiber is capable of enhancing the performance of SMA 20.

1. Introduction
Stone Mastic Asphalt (SMA), an asphalt paving mixture, gap-graded asphalt was originated in Germany in the1970s to provide maximum resistance to rutting caused by the studded tires on European roads [1]. SMA is made up from high coarse aggregate content that interlocks to form a stone skeleton that resists permanent deformation. Mastic of bitumen filled the stone skeleton and filler to which fibers are added to provide stability of bitumen and to prevent drainage of the binder during transport and placement [2]. Previous studies have shown that the use of Stone Mastic Asphalt (SMA) mix improves resistance to rutting and also increases pavemen durability compared to other types of asphalt mixture [3]. Main problems of SMA mixture is binder drain down during mixing, transport, and compaction. Drain down happen when a portion of the mixture fines and bitumen that separates itself from the sample as a whole and flow downward through the mixture. The main causes of binder drain down are high binder content in the mix and high temperature of the mix. The tendency of the binder to drain down during hot weather may cause premature failure of the mix [4]. Bamboo fiber has 43% cellulose, with a considerably higher percentage of lignin 31% [5]. The unique properties of bamboo come from the...
natural composite structure of fibers that consists mainly of cellulose microfibrils in a matrix of intertwined hemicellulose that made bamboo become stiff but decrease toughness. Present of fiber increase the stiffness of the asphalt binder resulting in stiffer combos with decreased binder drain-down and increased fatigue lifestyles. Mixtures containing fibers showed much smaller decrease in void content material and expanded resistance to permanent deformation. Thus, this study intended to utilize bamboo fiber as a modifier to improve the performance of stone mastic asphalt.

2. Methods

2.1. Materials
Stone mastic asphalt (SMA 20) were used for this study. The weight of aggregate each sample was 1200g with PEN 60/70. Bamboo as modified asphalt binder with 10mm length was mixed with different proportion which is 0%, 0.2%, 0.3%, 0.4%, 0.5% and 0.6%. Figure 1 shows the bamboo fiber.

![Figure 1. Bamboo Fiber.](image)

Table 1 shows the result of penetration, softening point, and ductility test, which all result shows that the tests are pass based on specification. Table 2 shows the result of Los Angeles Abrasion, AIV, Flakiness, and ACV all result shows that the test is pass based on specification. Table 3 shows the result SMA 20 aggregate gradation that used to design the specimen. All specification based on PWD Malaysia JKRSPJ, 2008.

| Table 1. Physical Properties of PEN 60/70 Binder [6]. |
|---------------------------------|---------------|-----------------|
| Asphalt Test                   | Asphalt Grade 60/70 | Standard Test Method |
| Penetration (mm)               | 65             | ASTM D5         |
| Softening Point (°C)           | 49             | ASTM D36        |
| Ductility (mm)                 | 150            | ASTM D113       |

| Table 2. Aggregate Physical Properties. |
|-----------------------------------------|---------------|-----------------|
| Testing                                  | Result        | Standard Test Method |
| Los Angeles Abrasion                     | 21.18 %       | ASTM 131        |
| Aggregate Impact Value                   | 15%           | BS812: Part 112 |
Flakiness Index 25% BS812: Section 105
Aggregate Crushing Value 13.5% BS812: Part 110

Table 3. SMA20 Aggregate Gradation.

| Sieve Size (mm) | Passing (%) | Retained (%) | Retained (g) |
|-----------------|-------------|--------------|--------------|
| 19.0            | 100         | 100.0        | 0            |
| 12.5            | 85-95       | 90.0         | 120          |
| 9.5             | 65-75       | 70.0         | 240          |
| 4.75            | 20-28       | 24.0         | 552          |
| 2.36            | 16-24       | 20.0         | 48           |
| 0.600           | 12-16       | 14.0         | 72           |
| 0.300           | 12-15       | 13.5         | 6            |
| 0.075           | 8-10        | 9.0          | 54           |
| Pan             | 0           | 0            | 108          |

2.2. Marshall Mix Design
Two specimens were prepared for each binder with 6.2% of the weight of total mix are used to evaluate Optimum Fiber Content (OFC). Two Marshall specimens for each Bamboo Fiber content (0%, 0.2%, 0.3%, 0.4%, 0.5%, 0.6%) were tested. In marshall mix design, the stability, stiffness, and density are determined to evaluate performance for every specimen. The optimum binder content (OBC) used is adopted from a study by Arshad et al. (2017) [7].

2.3. Resilient Modulus
The indirect tension was used to determine the resilient modulus of bituminous mixtures by applying compressive loads with a haversine waveform [8]. The resilient modulus value was obtained by elastic modulus based on recoverable strain under repeated load [11]. Two Marshall specimens for each Bamboo Fiber content (0%, 0.2%, 0.3%, 0.4%, 0.5%, 0.6%) were tested. Figure 2 shows the setup for the resilient modulus test.

Figure 2. Specimen in Universal Testing Machine.

2.4. Cantabro Loss
A total of 12 samples were prepared for this test, where 2 samples each for different percentage of (BF) which are 0%, 0.2%, 0.3%, 0.4%, 0.5% and 0.6%. Specimens were kept at a temperature of 25°C for six hours before testing. The specimens were weighed after it had been kept for the specified time and placed into the Los Angeles machine without the steel balls. Then, the drum was switched on at a velocity between 188 and 208 rad/s and subjected to 300 revolutions without steel ball. Figure 3 shows the specimen’s condition before and after the test.
Dynamic Creep

The creep compliance is determined by applying a dynamic compressive load of the fixed magnitude of 100 KPa for 2 hours at different temperature of 25℃ and 40℃ along the diametric axis of a cylindrical specimen. The resulting vertical deformation was measured by two LVDTs. In each test, the sides of the specimen were capped, and the sample was placed in the loading machine under the conditioning stress of 100 kPa for 600 s. Next, the conditioning stress was removed, and the main stress was applied for 3600 cycles, which included a 1-s loading period and a 1-s resting period. Figure 4 shows the setup for the dynamic creep test.

3. Results and Discussion

3.1. Marshall Stability

Based on Figure 5 (a), the results of density against fiber content shows that at 0.4% is the highest value compared to control sample at 0.0% by improvement 12.04 % due to bitumen filling the void space of aggregate. Based on Figure 5 (b), the results of stiffness against fiber content shows that 0.3% is the highest value compared to the control sample at 0.0% by improving 2.28%. High stiffness values indicate a mix with a greater ability to spread the applied load and resistance to creep deformation. Figure 5 (c) shows that at 0.4% of bamboo fiber contain, contribute the highest value compared to 0%, which is 6572.31N and 5789.88N by improving 11.9%. The highest value of stability indicating their higher rutting resistance and better performance compare to other different binder content [9,11].
3.2. Resilient Modulus

Based on Figure 6 (a), the result of resilient modulus at 25°C, higher Mr value obtained at 3000ms repetitive pulse period, where 0.3% gave the highest value which is 3816 MPa, compared to control which is only 1864 MPa. It shows improvement by increasing to 51.15% (0.4%) compare to the unmodified mixture. 3000ms represent the heavy traffic volume and based on the result when the load is applied for a longer period the asphaltic mix tends to be stiffer and more reduce rutting. Based on Figure 6 (b), the result of resilient modulus at 40°C, higher Mr value obtains at 3000ms repetitive pulse period, where 0.5% gave the highest value which is 2158 MPa, compared to control which is only 1332 MPa. However, it shows improvement by increasing to 38.28% (0.3%) compare to the unmodified mixture. 3000ms represent the heavy traffic volume and based on the result when the load is applied for a longer period, the asphaltic mix tends to be stiffer and more reduce rutting [7].

3.3. Cantabro Loss

From Figure 7, could see that 0% of fiber content obtained the highest value of cantabro loss compare to others. At 0.4%, the cantabro loss is lower compared to 0.3% of fiber content, which this value indicated that 0.4% is the optimum amount to be utilized to reduce abrasion loss of SMA 20. The lower amount of losses indicates the stronger bond between aggregate and binder at 300 revolutions.
3.4. Dynamic Creep

From Figure 8 (a) result of dynamic creep at 25°C shows that at 0.4% deformation are the lowest compared to 0% by reducing deformation to 68.93%. Hence, this can be concluded that at 0.4% of these specimens demonstrate lower rutting. Figure 8 (b) shows the result of dynamic creep at 40°C shows that at 0% deformation are the lowest compared to 0.4% by reducing deformation to 79.16%. Hence, this can be concluded that at 0.4% of these specimens demonstrate lower rutting. This test simulates the passage of moving traffic loads on the pavement to study the permanent deformation characteristics of bituminous materials and its ability to resist the creep distress under repeated load.
4. Conclusion

The findings of this study indicate that the existence of bamboo fiber is capable of enhancing the performance of SMA. Among the conclusions are the Cantabro Loss indicates that at 300ms (0.4%) the value of the loss is lowest compared to (0%) by reducing 59 %. Marshall stability test reported that at (0.4%) the value of stability, density and at (0.3%) the value of stiffness are highest compared to (0%) by increasing 2.28%, 12.04% and 44.29%. At 25°C, the resilient modulus shows improvement by increasing to 51.15% (0.4%) compare to the unmodified mixture while at 40°C, the resilient modulus result shows improvement by increasing to 38.28% (0.3%) compare to the unmodified mixture. Dynamic creep result at 25°C shows that at (0.4%) deformation are the lowest compared to (0%) by reducing deformation to 68.93% while at 40°C shows that at (0%) deformation are the lowest compared to (0.4%) by reducing deformation to 79.16%. From the test that had been conducted, the result obtained for Optimum Fiber Content is (0.4%) for SMA 20.

5. References

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