Resilient modulus of porous asphalt using oil palm fiber

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Abstract. In recent years, the use of waste fibers has been developing in many ways to increase the performance properties of asphalt mixture. Efforts to create a green technology which is more environmentally friendly that can produce economic value is also a consideration in the utilization of waste materials. The research is aimed to evaluate the resilient modulus of porous asphalt using oil palm fiber (OPF). Five different percentages of fiber (1%, 2%, 3%, 4% and 5%) were used by weight of bitumen. Several lab tests, such as characteristics, asphalts characteristics, and resilient modulus were carried out to compare and quantify performance of OPF-modified porous asphalt. In general, the results of experiments show that oil palm fiber addition to porous asphalt gives significant effect for its properties.

1. Introduction
Porous asphalt (PA) was developed in the early 50s in Europe and the United States. Usually, it is used for enhancing traffic and comforting drivers and occupants in the street of the region [1]. The utilization of PA in the top layers resulted on 20% air void content and interconnected micro voids are created due to higher proportions of coarse aggregates and lower sand content, which is in the wet weather cause the water depletes through a series of micro conduits [2].

PA also contains elimination of glare, splash and spray, improves visibility, increases skid resistance of the road surface [3, 4]. However, PA may experience problems which can affect its performance and service life due to the microstructure of PA. The open structure uncovered a large binder surface area to the oxidative impact of air and the damaging effect of water resulting from increased interfacial moisture content, leading to rapid aging of the binder, moisture damage of the bitumen aggregate bond and structural distress of the compounds [2].

Currently, many researchers have been used various types of fiber in asphalt mixtures, such as polyester fiber, cellulos fiber, glass fiber and mineral fiber to improve performances of pavements [5, 6]. Asphalt leakage during the material transportation and paving can be prevented through fiber stabilizing especially for the open-graded-friction-course (OGFC) and stone–mastic–asphalt (SMA) mixtures [7, 8]. The rheological properties of asphalt binder and the required optimum asphalt content for the mixture design are changed by the absorption of fiber in asphalt components, which is the important role in the formation of the interface bonding between fiber and asphalt [9].

Oil palm fiber (OPF) is squeezed out from empty fruit bunch fiber (EFB) [10]. The ability of the OPF in preventing the drain down of binders while improving the stability of the mix should lead to improving the stability of the mix which should lead to improved field performance [11]. Malaysia is one of major country in oil palm production which started about more than 70 years ago. It is reported by Palm Oil Board that there is 7.0 million tons of oil palm trunks, 26.2 million tons of oil palm fronds...
and 23% of Empty Fruit Bunch (EFB) per ton of Fresh Fruit Bunch (FFB) processed in oil palm mill. Based on these facts there will be ample amount of OPF available for use in suitable applications. However, there is not much study about use of OPF in asphalt road pavement. Therefore, it would be important to conduct an experimental laboratory study to investigate the use of this fiber in PA mixtures according to Malaysia condition.

The aim of this paper is to evaluate the effects of oil palm fiber (OPF) on some properties of porous asphalt (PA). Porous asphalt Grading-B using five different percentages of fiber were evaluated using laboratory tests. The performance of PA with respect to OPF additives were analyzed and evaluated using standard statistical techniques such as regression analysis and ANOVA.

2. Experimental program

2.1 Materials
Aggregates were employed from local crushed granite aggregate. The hydrated lime was added as filler. The aggregates were sieved into the selected size range according to the Malaysian Public Works Department for porous asphalt (PA-Grading B) as shown in table 1. The results of physical properties of aggregates tested are given in table 2. The conventional bitumen penetration-grade 80/100 was used. The physical properties of asphalt are presented in table 3. Oil palm fiber (OPF) produced by the palm oil industry in Malaysia is illustrated in figure 1 and the interior view of OPF at magnification 1.00KX is shown in figure 2. Table 4 illustrates the physical properties of OPF.

![Figure 1](image1.jpg) Figure 1. The oil palm fiber has to be washed to remove other materials before being sieved through a 425 μm sieve.

![Figure 2](image2.jpg) Figure 2. Interior View of OPF at Magnification 1.00KX.
Table 1. Gradation of porous asphalt (Grading-B) based on the Malaysian standard.

| Sieve size (mm) | Specification passing range (%) | Used passing (%) |
|-----------------|---------------------------------|------------------|
| 20.00           | 100                             | 100.0            |
| 14.00           | 85-100                          | 92.5             |
| 10.00           | 55-75                           | 65.0             |
| 5.00            | 10-25                           | 17.5             |
| 2.360           | 5-10                            | 7.5              |
| 0.075           | 2-4                             | 3.0              |

Table 2. Physical properties of crushed granite aggregate.

| Properties                              | Test method      | Test Value (%) |
|-----------------------------------------|------------------|----------------|
| Aggregate crushing value                | BS812:Part3      | 20.0           |
| Elongation index                        | BS182:Part3      | 16.0           |
| Flakiness index                         | BS182:Part3      | 4.0            |
| Impact value                            | BS812:Part3      | 20.0           |
| Los Angeles abrasion value               | ASTM C-131       | 21.0           |
| Soundness                               | BS812:Part3      | 4.1            |

Table 3. Physical properties of asphalt binder.

| Properties              | Test method | Unit | Test Value (%) |
|-------------------------|-------------|------|----------------|
| Ductility at 25°C       | ASTM D-113  | cm   | >100           |
| Penetration at 25°C     | ASTM D 5-97 | 1/10 mm | 84          |
| Softening point         | ASTM D-92   | °C   | 46             |

Table 4. Physical properties of OPF.

| Properties       | Unit     | Range |
|------------------|----------|-------|
| Density          | g/cm³    | 0.7-1.55 |
| Diameter         | μm       | 150-500 |
| Tensile strength | MPa      | 50-400  |

2.2 Specimen preparation

The oil palm fiber was washed to remove other materials and sieved through a 500 μm sieve. The binder contents (BC) used in the mix process were 4%, 4.5%, 5%, 5.5%, and 6% by weight of aggregate. Different percentages of fibers such as 1%, 2%, 3%, 4% and 5% by weight of bitumen were used to compare with control specimens (no fibers). Aggregates were mixed with asphalt binder at 160±5°C before adding fiber. The specimens were prepared using the standard Marshall hammer and tested to evaluate resilient modulus.

2.3 Test Method

Indirect tensile modulus test parameters are tabulated in table 4. According to the American Society Testing and Materials (ASTM) D4123-82, the Indirect Modulus test was carried out using the Universal Material Testing Apparatus (UMMATA) in order to apply compressive loads with acts parallel and along the vertical diametrical plane by two curves loading strips at 25°C. Following this, the information was sent to a computer program for data attainment. Horizontal tensile stress modulus of asphalt concrete mixtures can be obtained by equations (1).

\[ \sigma_x (\text{max}) = \frac{2 \times P}{\pi \times d \times t} \] (1)
Where $\sigma_{x}(\text{max})$ is the maximum horizontal tensile stress in middle of specimen; $P$, applied vertical peak load, $d$, average diameter of specimen and $t$; average thickness of specimen.

3. Results and discussion

Resilient modulus is an important parameter to analysis and determines the performance of pavement response to traffic loading [12]. The indirect tensile test with repeated loading at 25°C was used to determine the stiffness modulus of porous asphalt.

3.1 Effect of different OPF content on resilient modulus

The results for different contents of OPF on the resilient modulus are shown in figure 3 and the result of resilient modulus value with the different binder contents is shown in figure 4. For all particular binder contents, there appeared to be a maximum resilient modulus value as the OPF content increased from 0 to 5%. As expected, for any value of OPF content the resilient modulus value decreased as the binder content increased. This implied that the higher amount of binder at any particular OPF content would result in a more pronounced viscous component of the binder when compared to the elastic component, hence reducing the resilient modulus value.

![Figure 3. Resilient modulus value versus OPF content with the different binder content (BC).](image1)

![Figure 4. Resilient Modulus Value with the Different Binder Contents](image2)

3.2 Effect of different binder content on resilient modulus

Figure 4 illustrates the effect of different binder content on resilient modulus. From the available results, it seemed that the resilient modulus was high at 4% binder content and decreased at 6% binder content. This may have been due to increments in binder content. High amounts of OPF content were found to achieve the lowest resilient modulus. However, it was found that the resilient modulus of the mix with certain OPF contents had an inconsistent value. This indicated that the damage accumulation of the specimen is not a linear process.

3.3 Resilient Modulus at Optimum Binder Content

In this study, the optimum binder content was determined and selected as 5% for the oil palm fiber contents of 0%, 1%, 2%, 3%, 4% and 5%. The results of the resilient modulus at optimum binder contents are summarized in figure 4. As shown in figure 4, the results of the resilient modulus at the optimum binder content indicated that the mixes are generally higher than the specimen without fiber (0% OPF content) except for specimens made with 4% and 5% OPF content, with values of 1886Mpa, 1917Mpa, 1926Mpa, 1971Mpa, 1822Mpa, and 1761Mpa for fiber content 0%, 1%, 2%, 3%, 4% and 5% respectively.
4. Statistical analysis
Analysis of variance (ANOVA) was used as the statistical tool to evaluate the effect of OPF content on performance characteristics of porous asphalt. Two-factor ANOVA without replication and single factor ANOVA were adopted to evaluate the results of laboratory tests with confidence level 95% (α = 0.05). Table 5 presents the ANOVA result on the effect of fiber content on certain parameters of the porous asphalt. For the resilient modulus, the analysis gave an F-value of 122.93 (F=122.93 > F-critical= 2.866) and a P-value smaller than 0.05. As such, the addition of OPF significantly affects the properties and characteristics of the porous asphalt mixes.

Table 5. Results of ANOVA: Two-Factor without replication.

| Source of Variation | SS    | df | MS   | F      | P-value  | F crit |
|---------------------|-------|----|------|--------|----------|--------|
| Resilient modulus   |       |    |      |        |          |        |
| Binder content      | 713047| 4  | 178262| 122.93 | 8.82412E-14 | 2.86608 |
| OPF content         | 207898| 5  | 41579.6| 28.673 | 1.79741E-08 | 2.71089 |
| Error               | 29002.3| 20 | 1450.11 |       |          |        |
| Total               | 949947| 29 |      |        |          |        |

5. Conclusion
Based on this preliminary laboratory study, a number of observations and conclusions may be drawn. The resilient modulus value decreased as the binder content increased for any value of OPF content. This implied that a higher amount of binder at any particular OPF content would result in a more pronounced viscous component of the binder when compared to the elastic component, hence reducing the resilient modulus value. The results showed that inconsistent value of some relationships between OPF contents and binder contents indicated that the damage accumulation of specimens was not a linear process. From the results of regression analysis and analysis of variance (ANOVA), it was evident that the addition of oil palm fiber-modified significantly affected the properties and characteristics of the porous asphalt mixes.

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