Effect of Black PET Fiber as Additive on the Mechanical Properties of Stone Mastic Asphalt (SMA) Mixtures

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Abstract Stone Mastic Asphalt (SMA) is a type of gap-graded hot mix asphalt which consists of a coarse aggregates' skeleton and high binder content. This type of mixture has been used in many countries due to its toughness, stability and rut resistance mixture that relies on stone-to-stone contact for its strength and a rich mortar binder for its durability. On the other hand, there are some distresses that occur in SMA road pavement, which leads to a significant decrease in the life of the asphalt pavement. Therefore, the asphalt mixture needs to be modified by additive, such as fiber, to improve its mechanical properties and delay the deterioration. In this study, the influence of black PET fiber as an additive in the SMA mixture was focused. Six sets of asphalt mixtures were prepared using different proportions of black PET fiber content (0.2%, 0.4%, 0.6%, 0.8%, and 1.0% by the total mixture weight). Volumetric properties, Resilient Modulus, and Indirect Tensile Strength performance were investigated. The result showed that the optimum binder content for SMA mixture was 6.22%. It is also indicated that the use of black PET fiber as additive improved the Resilient Modulus and Indirect Tensile Strength performance. In conclusion, the use of Black PET fiber in SMA mixture indicates a positive potential to be applied in flexible pavement construction.

Keywords Black PET fiber · SMA mixture · Resilient modulus · Indirect tensile strength

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1 Introduction

Asphalt mixture is mainly constructed from three materials; aggregate (fine and coarse), asphalt binder, and filler. In SMA, there are small amounts of fine aggregates, which results in higher air void content that increase the mixture permeability. Drain down and raveling are considered common problems in SMA mixture, as it will usually lead to a significant decrease in the life of the asphalt pavement [1]. These problems led researchers to search for solutions to improve the mixture properties by incorporating various additives in the mixtures, especially fibers. Waste fibers that were used in asphalt pavement may come from different sources. Many studies focused on the use of waste fibers as additive in asphalt mixture such as; yarn bobbin [2], Posidonia oceanica [3], straw composite [4], coconut fibers [5–7], sisal leaves [5, 8–10], Jute plant fiber [11] paper mill sludge [12], date palm fibers [13, 14], oil palm fibers [15, 16], scrap tire fibers [17, 18], waste carpet fibers [17, 19], waste plastic fiber [20–23], kenaf fibers [24], Bagasse fibers [25, 26], Bamboo fiber [27], Banana fibers [7, 9], waste nylon wire [28], and wool [29, 30].

This research study focused on the use of black PET fiber as an additive in asphalt pavement. The primary objective of this study was to study the effect of black PET fiber on some mechanical properties of Stone Mastic Asphalt (SMA) mixture. The mechanical properties, namely, volumetric properties, resilient modulus, and indirect tensile strength tests were conducted on asphalt mixtures containing different content of black PET fiber (0.0%, 0.2%, 0.4%, 0.6%, 0.8% and 1.0%, from the total of mix weight).

2 Materials

2.1 *Asphalt Binder*

80/100 penetration grade was used in this study as the binder. The properties of the asphalt binder are presented in Table 1.

Table 1 Properties of asphalt binder

Property	Temp	Unit	Reference	Value	Requirement
Penetration	25 °C	0.1 mm	ASTM-D0005	87	80–100
Softening Point	–	°C	ASTM-D0036	46	45–52
Rotational Viscosity	135 °C	Pa s	ASTM-D4402	0.31	< 3000
Rotational Viscosity	165 °C	Pa s	ASTM-D4402	0.1	< 3000
Specific Gravity	25 °C	–	ASTM-D0070	1.020	–
G*/sinδ	58 °C	kPa	ASTM-D7175	1.576	> 1.0

2.2 Aggregates

The crushed granite aggregates used in this study were collected from the same aggregate supplier to maintain the quality and results in reliability. The aggregate gradation used in this study was Stone Mastic Asphalt (SMA) 20, that is accordance to the specification of the Malaysian Public Works-Road Department (JKR) [31], as shown in Fig. 1. Meanwhile, the physical properties of granite aggregates for SMA20 are tabulated in Table 2.

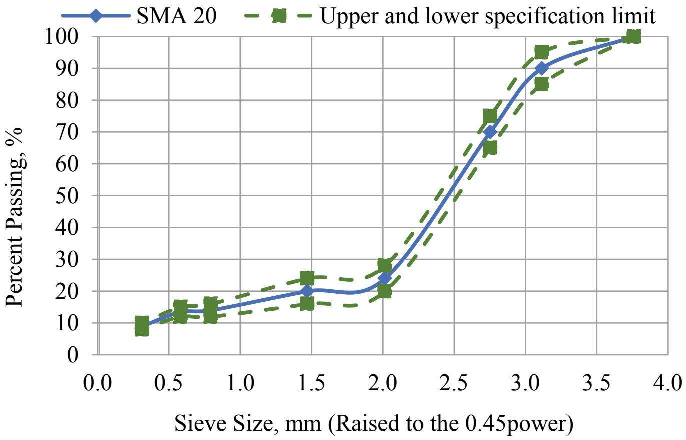

Fig. 1 SMA20 aggregate gradation

Table 2 Physical properties of SMA20 granite aggregate

Property	Test method	Value	KJR requirement
Los Angeles abrasion	ASTM: C131-14	19.8%	<25%
Flakiness index	BS 182: Part3	7.3%	<25%
Elongation index	BS 182: Part3	13.4%	<20%
Impact value	BS 812: Part3	10.3%	<15%
Specific gravity of coarse aggregates	ASTM C-127	2.61	–
Water absorption of coarse aggregates	ASTM C-127	0.65%	<2%
Specific gravity of fine aggregates	ASTM C-128	2.59	–
Water absorption of fine aggregates	ASTM C-128	1.19%	<2%

2.3 Black PET Fiber

Black PET fiber was used as an additive in this study. Black PET fiber was obtained from a local factory which involves in the interior fitting for the automotive industry in Malaysia. The waste black PET fiber was loosed, and cut into small pieces with an average length of 4 mm (Fig. 2). According to JKR specification [31], the fiber length should be less than 6 mm if it is to be used as an additive in the SMA mixture. The physical properties of black PET fiber are tabulated in Table 3.

Fig. 2 Loose black PET fiber

Table 3 Physical properties of black PET fiber

Property	Unit	Value
Dimeter	microns	40
Length before cut	mm	77
Length after cut	mm	4
Elongation	%	67
Shrinkage	%	3.6
Moisture	%	0.4
Density	g/cm^3	1.38
Water solubility	–	Insoluble

3 Mix Design and Experimental Program

Six different asphalt mixture proportions were prepared. The first one was the control mixture. In the other five mixtures, the black PET fiber was used as an additive with the percentages of 0.2%, 0.4%, 0.6%, 0.8%, and 1.0% by the total of mixture weight. The SMA mixture samples were prepared using Marshall Mix Method in accordance to ASTM D6926 [32] and the Malaysian Public Works-Road Department (JKR) [31]. Meanwhile, the SMA mixtures with black PET fiber incorporation were mixed through the dry process. Three duplicates samples were weighted for each combination of aggregates mixture. The aggregates were put in the oven for 3 hours at the temperature of 160–170 °C. Meanwhile, the asphalt binder was heated up to a mixing temperature of 150–155 °C for 1 hour. The blended mixture was compacted using 50 blows at each side at a temperature of 140–145 °C. The samples were kept in the moulds for 24 hours. The samples were remoulded after 24 hours and were kept for related tests. Through the Marshall stability and flowability test, the optimum binder content was determined. Through calculation, the optimum binder content for SMA mixture was 6.22%.

4 Mixture Performance Tests

To evaluate the mechanical properties of SMA20 mixtures, the samples were tested for different tests such as volumetric properties, resilient modulus test, and indirect tensile strength test. Each test is described in the following sections.

4.1 Volumetric Properties

Volume of asphalt binder and aggregates is highly affected by the volumetric properties of the required asphalt mixture. The volumetric properties of the asphalt mixture are among the critical factors that affect pavement performance and durability [33, 34]. In the SMA mixture, the air voids were considered to be one of the main factors in the mix design [6, 35–37]. In this study, the volumetric properties, such as density, air voids, and voids in mineral aggregate (VMA) were calculated. The density was determined according to D2726 [38], and the air voids and VMA were determined according to D3203 [39].

4.2 Stiffness Modulus Test

The stiffness or resilient modulus test was carried out using a universal materials testing apparatus (UMATTA) machine, in accordance with ASTM D4123 [40]. The samples were prepared with an average of 101.7 mm diameter and 65 ± 1 mm thickness. The test was carried out at the temperature of 25 °C. The resilient modulus of the samples was calculated automatically based on the following equation:

$$\text{StiffnessModulus(MPa)} = \frac{P(\nu + 0.25)}{HxT} \quad (1)$$

where, P is the peak load (N); v is the Poisson's ratio; T is the average thickness of the sample (mm) and H is total recoverable deformation on the horizontal axis (mm). Each sample was tested three times. The position of the vertical dimension plan of the cylindrical sample was modified for each test. Finally, the results of the three duplicate samples were averaged and recorded.

4.3 Indirect Tensile Strength Test

According to AASHTO-T283 [41], the purpose of this test is to determine the tensile strength along the diametral direction of compacted asphalt mixture samples. Three duplicate samples with 101.6 mm diameter and 65 ± 1 mm length were prepared and compacted to achieve about 7.0% air voids. The test was carried out at the temperature of 25 °C, and the load was applied on the diametral direction at a constant deformation rate of 50 mm/min. The load at failure was recorded to calculate the tensile strength, as follows:

$$S_t = \frac{2000xP}{\pi xTxD} \quad (2)$$

where, St denotes tensile strength (KPa), P signifies maximum load (N), T refers to sample thickness (mm), and D indicates sample diameter (mm).

5 Results and Discussion

5.1 Volumetric Properties

The effect of black PET fiber content on the volumetric properties such as the bulk density, air voids, and VMA are graphically presented in Figs. 3, 4 and 5, respectively.

Figure 3 indicated that black PET fiber affected the density of the mixture as the density of the compacted sample decreased with an increment in black PET fiber

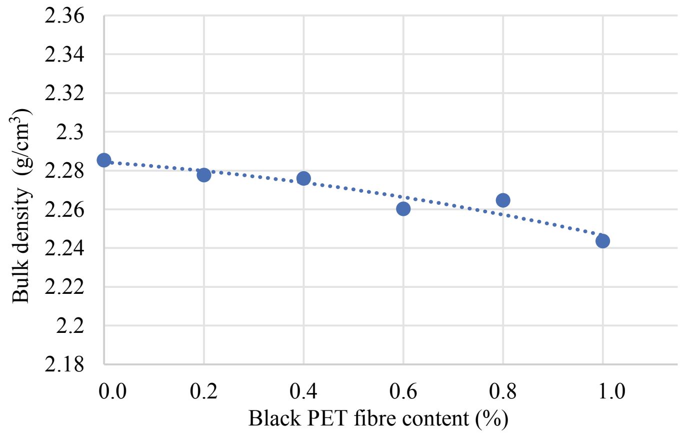

Fig. 3 Bulk density for different black PET fiber mixtures

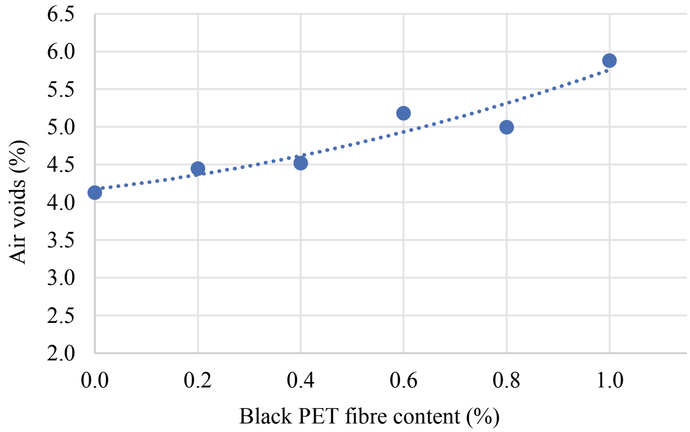

Fig. 4 Air voids for different black PET fiber mixtures

content. Furthermore, all the mixtures with black PET fiber additive showed lesser density values compared to the control mixture. This is because of the lower specific gravity of black PET fiber (1.39) as compared to the aggregates (2.62).

Figure 4 showed the mixtures air void values versus black PET fiber. All the mixtures air voids were within the range except mixture with 1.0% fiber showed higher value, 5.9%. Additionally, the figure indicated that with an increase in the black PET fiber content, the air void values of the mixture will also increase. The observation signifies that by adding black PET fiber to the SMA mixture, it will affect the mixture air void values. Apparently, the performance of the asphalt mixture is dependent on the air voids in the mix. For SMA mix, the air voids should be 3–5% [31]. Too many air voids in the mixture will lead to asphalt cracking due to low

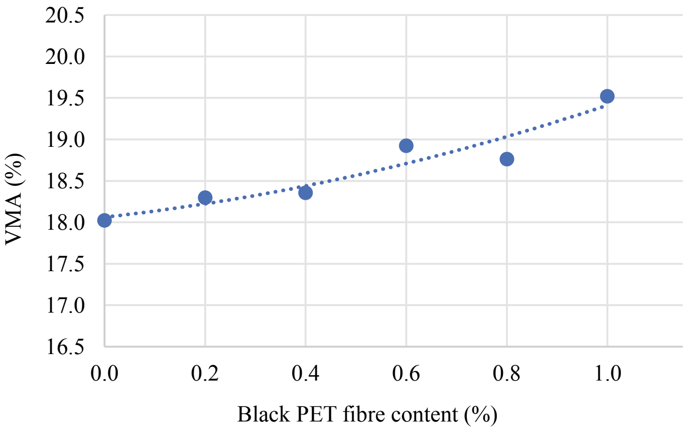

Fig. 5 VMA for different black PET fiber mixtures

asphalt binder content, resulting in its failure to coat the aggregates in the mixture, while too few air voids in the mixture may result in more deformation and asphalt binder bleeding [42].

Figure 5 showed the values for different black PET fiber mixtures. All mixtures fulfilled the standard requirement of the minimum value of VMA for SMA mixture, that is, 17% [31]. The results showed that the VMA value increased as values black PET fiber content increased. As the stems from the fibrous material was added to the mix, the fiber increases the resistance to the sample compaction, hence resulting in VMA increment value.

5.2 *Stiffness Modulus Result*

Figure 6 presented the stiffness modulus for different black PET fiber mixtures. It can be seen that the resilient modulus value of mixtures with black PET fiber showed higher stiffness as compared to the control mixture. Moreover, the stiffness modulus value increased by the increment of black PET fiber content until 0.6%. The stiffness modulus value for 0.6% was 12,867 N/mm^2. This increment was probably due to the black PET fiber, in where it binds and restricts the movement of aggregates. This makes the asphalt mixture become stiffer. Whereas, the resilient modulus value decreased at 1.0% for black PET fiber. The decrement of the stiffness modulus values was most likely attributed to the high surface area of black PET fiber, that need to be coated by the asphalt binder. Therefore, the aggregates and fibers were not fully coated by the binder, hence resulting in the asphalt mixture become less stiff.

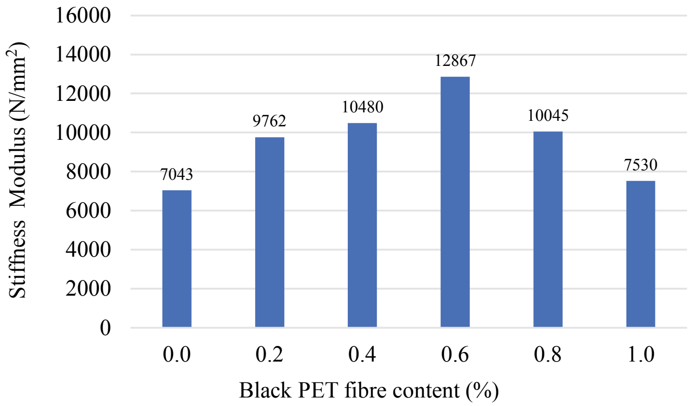

Fig. 6 Stiffness modulus for different black PET fiber mixtures

5.3 Indirect Tensile Strength Result

Indirect tensile strength values for different black PET fiber mixtures are presented in Fig. 7. Clearly, the addition of black PET fiber increased the indirect tensile strength of asphalt mixture. All mixtures with black PET fiber had higher strength values than control mixture (without fiber). Furthermore, the indirect tensile strength value increased until it reached the maximum value of 699.9 kN/m^2 for mixture with 0.6% fiber. However, the indirect tensile strength value was decreased when the black PET fiber was increased to 1.0%. Based on these results, the asphalt mix with 0.6% fiber appeared to be the optimum mixture, which showed better performance as compared to the other mixtures.

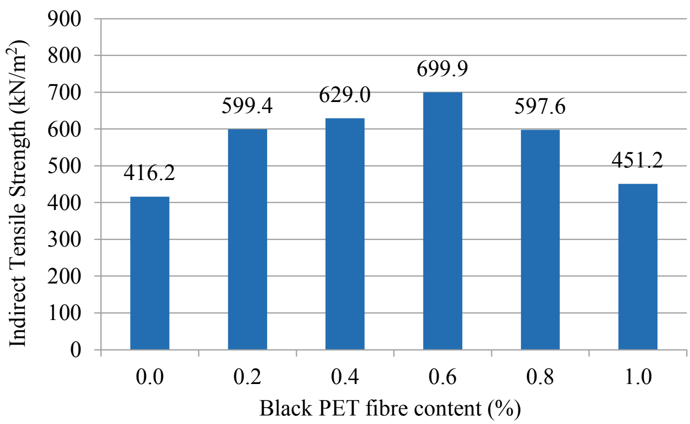

Fig. 7 Indirect tensile strength for different black PET fiber mixtures

6 Conclusion

In this study, the feasibility of using black PET fiber as an additive in SMA mixture is investigated. Based on the results and analysis, the following conclusions are derived:

(1) From volumetric properties, it can be concluded that using black PET fiber as an additive in the SMA mixture posed insignificant effect on the mixture's density, air voids, and VMA. The addition of black PET fiber decreased the density and increased the air voids, and VMA of asphalt mixture.
(2) For stiffness modulus performance, the stiffness modulus value increased by the increment of black PET fiber, which indicate that the SMA mixtures with black PET fiber will result in a high rutting resistance.
(3) For indirect tensile strength performance, the strength value increased by the increment of black PET fiber. Hence, adding black PET fiber to SMA mixtures will enhance the strength property and made it stiffer.
(4) Overall, the black PET fiber was found to be appropriate to be used as an additive in SMA mixture. The optimum percentage of black PET fiber was found to be 0.6% from the weight of the total mix. Hence indicating better performance in comparison to the other mixtures.

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