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PERFORMANCE OF STONE MASTIC ASPHALT MIX USING SELECTED FIBRES

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Graphical abstract

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. However, binder draindown is a problem for SMA mixtures, due to its intentional high binder content. This paper details the performance evaluation of two different cellulose fibres used in SMA14 mix; synthetic fibre (Viatop66) and natural fibre (Kenaf) to prevent binder drainage. The cellulose fibres, 0.3 percent by weight of the mixture, were uniformly combined with the dried aggregate before the asphalt cement was added during mixing process. Laboratory specimens were prepared using 50 blows of the Marshall hammer per side. The Optimum Binder Content (OBC) for the SMA14 mix with Viatop66 was found to be 6.1 percent, while the OBC for the SMA14 mix with Kenaf was found to be 5.9 percent. Rut depth obtained for SMA14 mix Kenaf was lower (1.6 mm) compared with SMA14 mix with Viatop66 (1.8 mm). The tensile strength ratio recorded for both mixes are greater than 80 percent, indicating adequate stripping resistance. The fibres were found to interact well with other substances in the SMA14 mix using the Environment Scanning Electron Microscopy (ESEM). This indicates that the natural fibre could efficiently retain the binder in the mix. Therefore, natural fibre (Kenaf) could be an alternative material to replace the synthetic fibre for the SMA14 mixture.

Keywords: Stone mastic asphalt, synthetic fibre, natural fibre

1.0 INTRODUCTION

Stone Mastic Asphalt (SMA) originates from Germany in the 1970's and is used as an asphalt mixture to provide maximum resistance to rutting [1]. One of the main problems of SMA mixture is binder draindown during mixing, transport, and compaction. Draindown occurs when the bitumen runs off through the aggregate during delivery or in the hopper of the paver. The main causes of binder draindown are high binder content in the mix and high temperature of the mix [2]. The tendency of the binder to draindown during hot weather may cause premature failure of the mix. To overcome this problem, fibres are usually added to SMA mix as drainage inhibitor.

Synthetic fibre, such as Viatop66 has been widely used successfully in the original specification of the SMA mixtures. However, as this product is currently being imported from Germany, it increases the cost of SMA in Malaysia by about 20 percent [3]. As an alternative to resolve this problem, Kenaf fibre, a type of natural fibre found in Malaysia, was selected in this study to be used for SMA mixture for a cost effective solution.

Kenaf is used in this study as it is one of the locally available fibres that are widely used by researchers in several different areas due to the multi-usage of its cellulose content [4]. Its scientific name is Hibiscus Cannabinus, and it is one of the non-wood lignocelluloses that grows well in tropical and sub-tropical areas [5]. The use of Kenaf fibre in SMA mixture is worth to be investigated as the availability of Kenaf resources in Malaysia will result in lower production cost of SMA pavements. In addition, it can also be considered as an eco-friendly material, which promotes sustainability in pavements.

Hence, the main goal of this study is to evaluate the performance of stone mastic asphalt (SMA) mix using Kenaf, a natural fibre, and to compare its performance with a commonly used synthetic fibre, Viatop66.

2.0 EXPERIMENTAL

The gradation of the combined coarse aggregate, fine aggregate and mineral filler were chosen to conform with the appropriate envelope in accordance to PWD Malaysia's Standard Specification for Road Works [6]. Figure 1 shows the aggregate gradation curve of the SMA14 mixture.

The SMA14 mixtures were prepared in accordance with the Marshall Method as specified in ASTM D1559 [7]. Samples were prepared using synthetic fibre (bitumen precoated pelletized cellulose fibre Viatop66 as shown in Figure 2, and natural (Kenaf) fibre as shown in Figure 3. The SMA14 mixtures were prepared with different percentages of binder content (5% to 7%). The dry process method was used during the addition of the fibres before being mixed and blended with the bituminous binder.

For SMA14 mixture with natural fibre, the fibre was cut into small pieces (6mm maximum), before it was added directly to the aggregate sample. The samples were then placed into the oven for 2 hours to simulate the aging process. The mixtures were then poured into preheated Marshall moulds, and the samples were prepared using 50 blows of the hammer on each side. The specimens were kept overnight to be cooled at room temperature. The Marshall method was then used to obtain the volumetric properties of both SMA14 mixtures.

Binder draindown test was determined placing the mass of loose SMA14 mixture in a basket. For this study, the samples were prepared at optimum binder content. Then, the filled basket was positioned above a pre- weighed stainless steel plate in an oven for three hours at a temperature of 170°C. At the end of three hours, the filled basket was removed from the oven along with the stainless steel plate and the plate was weighed to determine the amount of draindown that occurred.

Moisture susceptibility test was performed following the procedures described in AASHTO T 283 [8]. Samples for the test were prepared at 7 $\pm$ 0.5 percent air voids.

Dynamic modulus test was performed in accordance to AASHTO TP62 [9]. Temperatures of 25, 40, and 55°C and loading frequencies of 25, 20, 10, 5, 1, and 0.5 Hz were used at confining pressure of 100 psi.

The Automated Asphalt Pavement Analyzer (APA) was used for the rutting susceptibility test in accordance to AASHTO TP63 [10]. Gyratory compactor was used to compact the samples until 7.0 $\pm$ 0.5 percent of air voids obtained. The samples were then preheated in the temperature calibrated APA test chamber for 6 hours. The test length was set to 8000 cycles.

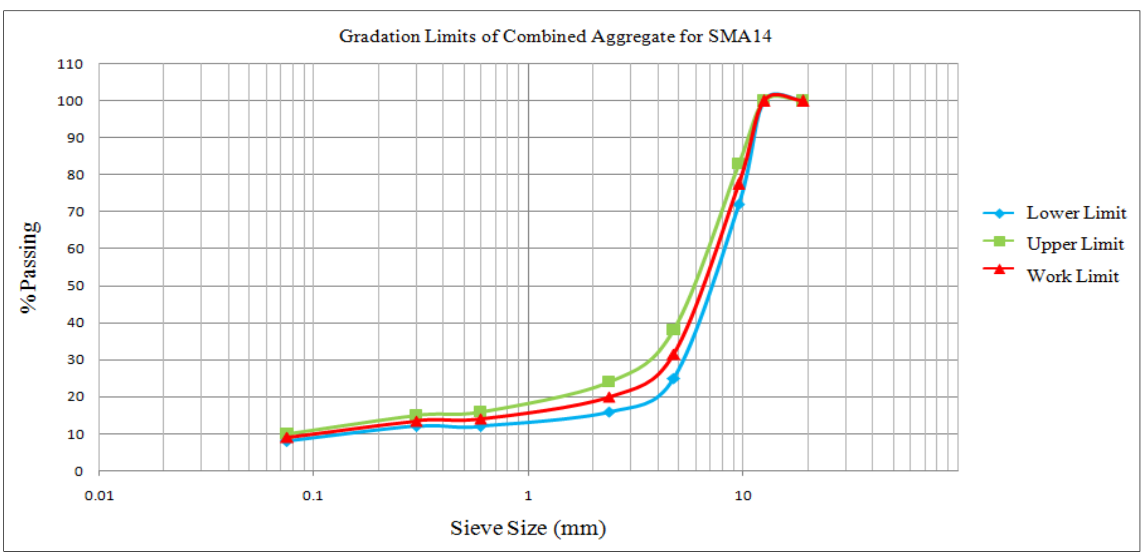

Figure 1 Aggregate gradation Curve for SMA 14 Mix

Figure 2 Synthetic Fibre (Viatop66)

Figure 3 Natural Fibre (Kenaf)

3.0 RESULTS AND DISCUSSION

3.1 Volumetric Properties

Table 1 shows the results of volumetric properties of SMA14 mixtures using selected fibres according to Marshall method. SMA14 mixture with natural fibre contained higher values of air voids compared to SMA14 mixture with synthetic fibre. This might also be the likely cause of the higher flow for the natural fibre, which is slightly above (4.1mm) the specification requirements. The optimum binder content for the SMA14 mixtures with synthetic and natural fibres were found to be 6.1%, and 5.9%, respectively.

Table 1 Volumetric properties of the SMA14 Mixtures

Volumetric Properties	SMA Mix Requirements	Natural Fibre	Synthetic Fibre
Stability, N	Min 6200	11600	12400
Flow @ 3mm	2 - 4	4.1	2.9
Air Voids in Total Mix @ 4%	3 - 5	4.3	3.6
Air Voids in Mix Aggregates, %	Min 17	19.1	19.3
Optimum Bitumen Content (OBC)	5.7 - 6.5	5.9	6.1

3.2 Binder Draindown

Binder draindown was calculated as the percentage of the binder that drained out from the basket by using Eq. (1).

$$\text{Binder Drainage (\%)} = [(C-B)/A] \times 100 \qquad (1)$$

where,

A = Mass of initial total sample (gram);
B = Mass of initial plate (gram); and
C = Mass of the final plate (gram)

PWD Malaysia's specifications states that the maximum draindown value is 0.3% of the total of mixture. The percentage of binder drainage for each SMA14 mixture is presented in Figure 4. Both mixes with natural and synthetic fibres met this requirement with draindown values of 0.032% and 0.040% respectively. The addition of fibres into the mix allows the asphalt to be more viscous and provides the ability to retain the asphalt during the drain out process when temperature increases.

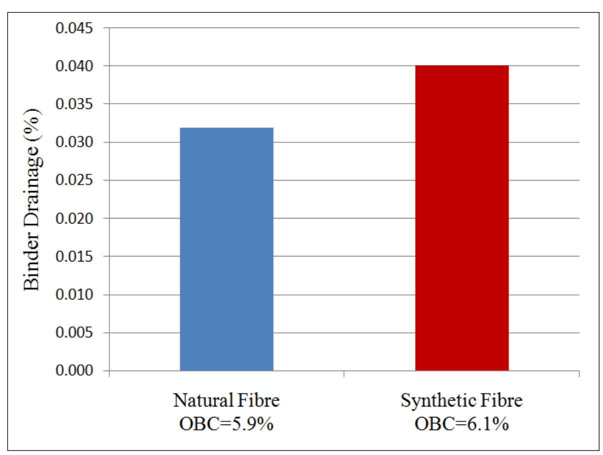

Figure 4 Binder Draindown for SMA14 Mixes

3.3 Moisture Susceptibility

Moisture susceptibility test was performed in accordance to the procedure described in AASHTO T 283. Figure 5 shows the value of tensile strength ratio (TSR) for both types of mixes. The tensile strength ratio (TSR) for synthetic fibre mix is 0.83 compared to 0.81 for the natural fibre mix. This indicates that the TSR ratio for synthetic fibre mix is higher than natural fibre. However, the tensile strength ratio recorded for both mixes are still greater than 80 percent that is required for adequate stripping resistance.

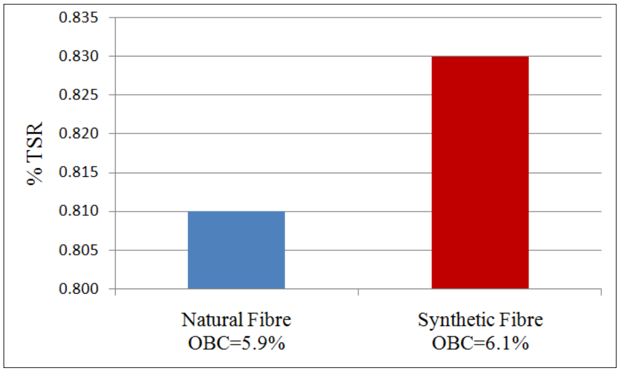

Figure 5 Tensile Strength Ratio (TSR) for SMA14 Mixes

3.4 Dynamic Modulus

Figure 6 shows the dynamic modulus values for mix with natural fibre while Figure 7 shows the dynamic modulus values for mix with synthetic fibre at various temperatures and loading frequency settings.

It could be seen from both figures that the dynamic modulus for both mixtures decreases with the decrease of loading frequency; also when the temperatures increase, the dynamic modulus decrease. Although the dynamic modulus values for the mix with synthetic fibre is higher at 25°C for all load frequencies, the mix with natural fibre has higher dynamic modulus values at 40°C and 55°C. This could be due to the fact that the natural fibre could withstand higher temperatures compared to synthetic fibre.

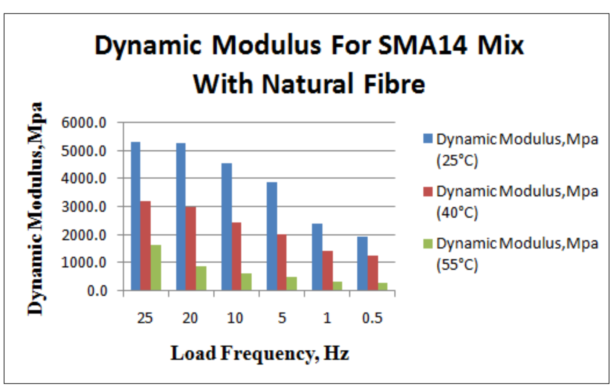

Figure 6 Dynamic Modulus for mix with natural fibre

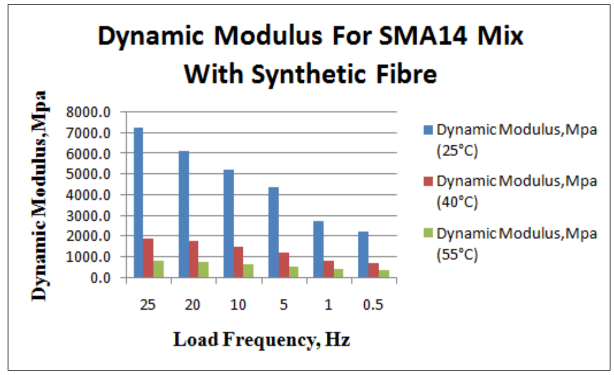

Figure 7 Dynamic Modulus for mix with synthetic fibre

3.5 Rutting Test

Figure 8 shows the results of the rutting test carried out using the Automated Asphalt Pavement Analyzer (Automated APA). From Figure 6, it could be seen that the rut depth for both mix increases with count of stroke under repeated passes of a loaded wheel. After the completion of 8000 cycles, the rut depth measured for synthetic fibre is 1.834mm and for natural fibre mix is 1.602 mm. The higher rut depth value for synthetic fibre is likely due to the higher value of binder content use in the mix.

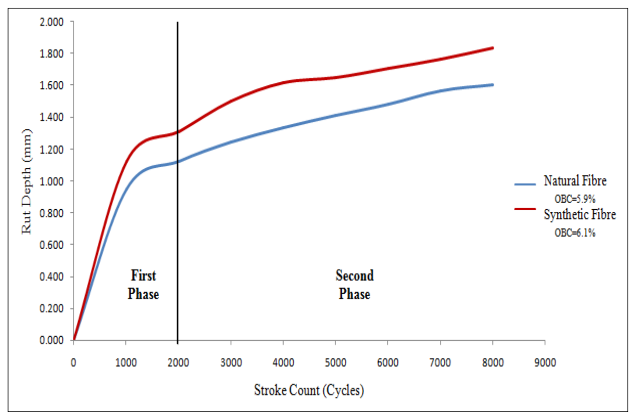

Figure 8 Rut Depth using APA for both mixes

3.6 Environmental Scanning Electron Microscopy

The orientation of the fibres in the mixes was examined with the environment scanning electron microscopy (ESEM). ESEM was carried out onto cut sample blocks to visualize the synthetic nad natural fibre interaction with the SMA14 mix. From the ESEM micrograph of both SMA14 samples, the interaction of the fibres with bitumen and aggregate minerals can be examined. The details of ESEM micrograph are shown in Figure 9 for mix with synthetic fibre and Figure10 for mix with natural fibre. Based on the observation of the figures, it could be seen that the voids in SMA14 were filled with fibres and both fibres interact well with the others substances. This indicates that the natural fibre has efficiently retained the binder in the mixes.

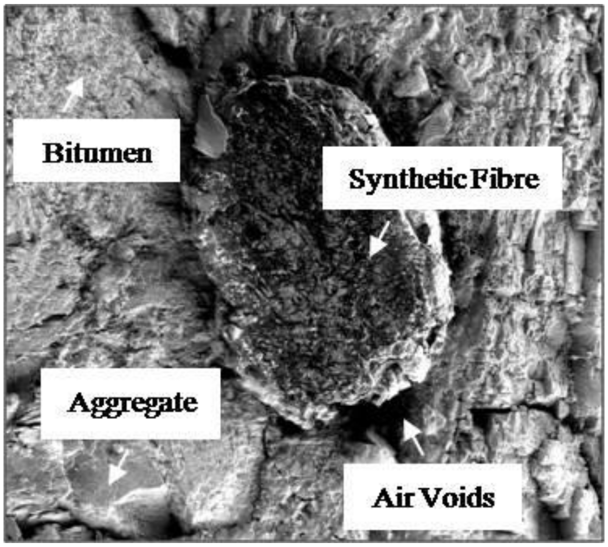

Figure 9 SMA14 with Synthetic Fibre (Magnification 500 X)

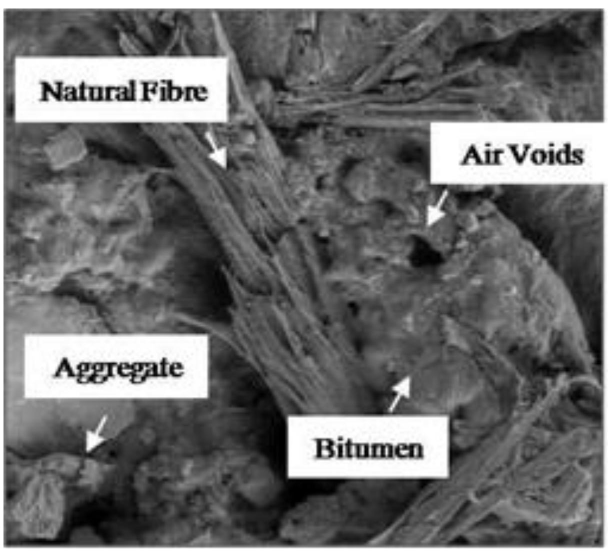

Figure 10 SMA14 with Natural Fibre (Magnification 500 X)

4.0 CONCLUSION

Based on the results obtained, it was observed that the performance of SMA14 mixture was significantly affected with the addition of selected fibres as stabilizing agent. Utilization of selected fibres in the mixture can affect the volumetric properties, binder drainage, tensile strength, and performance to resist rutting of the mixes. From the results of the laboratory work, the following conclusion can be made:

- SMA14 mixture using natural fibre has a slightly lower OBC compared to synthetic fibre.
- SMA14 mixture using natural fibre shows better ability to retain the binder draindown of the mixture compared to synthetic fibre.
- Although natural fibre has a lower TSR value, both mixes have TSR values of greater than 80 percent that is required for adequate stripping resistance.
- Natural fibre shows higher resistance to rutting compared to synthetic fibre.
- Natural fibre has higher dynamic modulus values at 40°C and 55°C compared to synthetic fibre, indicating a possible better performance at higher temperatures.

Therefore, it can be concluded that natural fibre such as Kenaf could be an alternative material to replace the synthetic fibre for SMA mixes.

Acknowledgement

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