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Effect Of Different Kenaf Core Contents And Sizes As Filler On The Properties Of Road

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Abstract

Kenaf core is less utilised due to its shorter fibre compared to kenaf bast and it is a waste to discard kenaf core fibre since it consists 60% dry weight of the stem. This study was conducted to investigate on the utilisation of kenaf core as alternative filler in hot melt asphalt (HMA) mixtures. HMA mixtures containing kenaf core at various percentages; 0.3%, 0.5%, and 0.7% and sizes; 75 µm and 150 µm were produced. Indirect Tensile Modulus Test was used to evaluate the properties of the sample blocks produced. Results show that 0.3% is the optimum percentage of kenaf core powder and fibre as filler content in HMA according to its value of resilient modulus compared to 0.5% and 0.7%. The more content of kenaf core were added into the mixtures would create higher air voids. This is because additional content or size of kenaf core in mixture was able to reduce adhesion between the aggregates with bitumen. Moreover, the more content of kenaf core added into mixture resulted in reduction of the value of resilient modulus at 25°C when the increasing traffic loads from 1000 N to 3000 N were applied to the produced sample blocks. The value of resilient modulus obtained which is lower than the Public Works Department (JKR) specification caused the road to be less rigid in sustaining stress and deformed road in a short period of time.

Keywords: Kenaf core; Hot Mix Asphalt (HMA); Filler; Bitumen; Resilient modulus; Traffic loading; SEM

Introduction

Kenaf (*Hibiscus cannabinus* L., Malvaceae), is one of the non-wood lignocelluloses that grows well in tropical and sub-tropical areas. It is one of the fast-growing plants which complete its maturity in 150 days. Kenaf is harvested for its stalk, which can reach height in the ranged of 2.5 m to 6 m depending on environmental conditions. Kenaf stalk consists of two separate parts known as bast and core. The bast is an external bark with fibres ranged from 3 mm to 4 mm long while the core is an inner thick core of short woody fibres ranged from 0.5 mm to 1 mm long which stand approximately 35% and 65% of the stalk mass respectively.

Kenaf core fibre has relatively low-value uses compared to kenaf bast as the bast fibres are of better quality than the core fibres (Hazandy *et al.*, 2009). Jonoobi *et al.* (2009) also stated that the bast fibres have been found to possess attractive mechanical properties and has been used as an alternative source for production of pulp, nonwoven fabrics and reinforced composite materials in automotive, aerospace, packaging and other industries applications due to the fibres' mechanical properties (Ayre et al. 2009). Application of kenaf core is not well established and often considered as waste. However, according to Lips *et al.* (2009), studied done on water absorption characteristic of kenaf core has shown its usage in producing animal bedding material.

In this study, the utilisation of kenaf core is extended to road construction where it can be used as alternative filler to the commonly used Portland cement in Hot Mix Asphalt (HMA) to reduce the cost of road construction. HMA is one type of premix that is used widely in road construction in Malaysia. It can be said that, all main roads whether in rural or urban areas are paved with HMA. HMA is a combination of asphalt binder (bitumen) which is a by-product of the petroleum distillation process and aggregate that obtained from rock quarries or riverbeds.

This study was aimed to determine the effect of kenaf core as alternative filler in road construction with regards to different contents and sizes.

Materials and Methods

Kenaf cores were obtained from Kota Marudu, Sabah. They were cut, chipped, grinded and sieved to obtained core materials with 75 µm (powder) and 150 µm (fibre) in size as fillers. Sieved materials were oven-dried before kept in plastic bag.

Hot Mix Asphalt (HMA), premix was obtained from a local road construction company. The aggregate gradation was ACW20 according to the specification of Public Works Department (JKR). Bitumen with penetration grade 80/100 was used in this study. The specific gravity of bitumen was 1.03. The bitumen content for these samples was 5.79% which was in the range of 4.5% - 6.5% according to the specification of JKR.

Firstly, HMA premix was heated and mixed together with kenaf core for 15 minutes at 160°C. The amount of kenaf core material added into the asphalt mixture were 0.3%, 0.5% and 0.7% of the total weight of asphalt mixture in two different sizes 75 µm and 150 µm. After mixing, the mixture was placed inside the mould of 10 cm diameter and compacted with 75 gyrations which was applied in medium-trafficked roadways using Superpave Gyratory Compactor (SGC). HMA-Kenaf core sample blocks were obtained after compaction. Each sample block weighed about 1200g.

The sample blocks were then conditioned for 24 hours at 25°C in the UTM-5P chamber. Different traffic loadings (1000 N, 2000 N and 3000 N) were tested on the sample blocks through Indirect Tensile Modulus Test where results of resilient modulus were obtained according to ASTM D4123-82 (ASTM, 2004). Control sample block with only HMA was produced as comparison.

Specific gravity of every sample block was determined according to the standard of ASTM C 127 (ASTM, 2004). The Theoretical Maximum Density (TMD) in this study was 2.37 which determined by the equation:

$$\text{TMD} = \frac{100}{[\,(A / B) + (C / D)\,]}$$

Where,

A = Percentage of bitumen, %
B = SG bitumen
C = Percentage of aggregate, % (100 - A)
D = SG aggregate

The percentage of air voids (Voids in Total Mix, VTM) for HMA was defined as voids volume between the aggregates coated by bitumen which was generally associated with durability and strength of the mixture. The specification of VTM was 3.0% - 5.0% by JKR. VTM was determined by the equation:

$$\text{VTM} = 100 - (100\ \text{SG} / \text{TMD})$$

Scanning electron microscope was carried out onto cut cubes (1 x 1 x 1) cm to visualise the air voids present in the sample blocks.

Results and Discussion

The percentage of kenaf core materials added to the HMA varied at 0.3%, 0.5% and 0.7% on 2 sizes (75 µm and 150 µm). The average percentage of air voids and resilient modulus values of the different traffic loading at 25°C were determined and evaluated through data analysis.

Air voids

Overall, the result showed that the higher percentage of kenaf core content was added into the mixture, the higher was the percentage of air voids was present regardless of sizes. Based on Table 1, result shown increment in the average percentage of air voids as the percentage of kenaf core content was increased. Similar result stated in Khadjijah (2005) where the average percentage of air voids obtained was increased while the percentage of oil palm fly ash content increased. The oil palm fly ash had been mixed with various content percentages 1.0%, 2.0%, 3.0%, 4.5%, 5.5%, and 6.5% in the size of 75 µm. The results of the percentage of air voids obtained in her study were 3.0%, 3.5%, 2.6%, 6.0%, 5.6%, and 5.5% while the percentage of air voids of control sample block was 3.2%.

Images of air voids and kenaf core fibres from Scanning Electron Microscope (SEM) were shown in Figure 1.

Figure 1 : (a) Air voids in the sample block with magnification 100 X, (b) The voids were filled with kenaf core fibres with magnification 500 X.

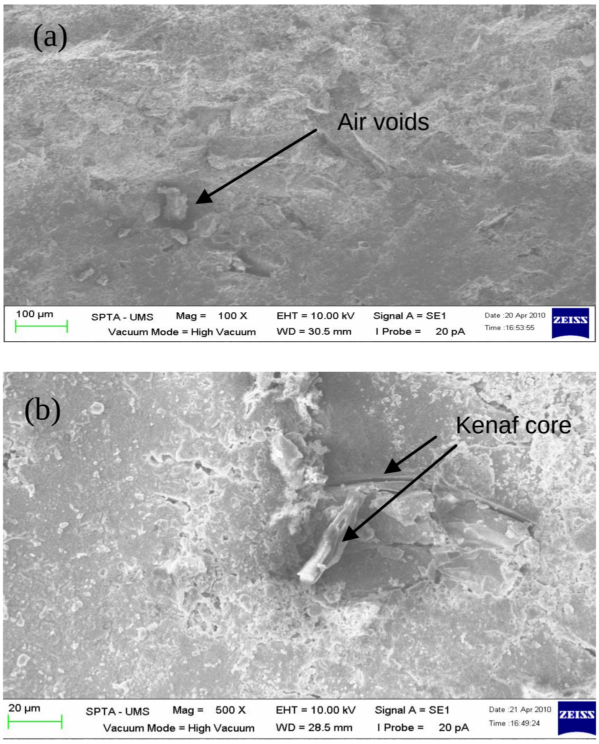


Table 1 : Average percentage of air voids compared to the percentage of kenaf core content.

Kenaf core size (µm)	Percentage of kenaf core content (%)	Average of percentage of air voids (%) [#]
75	0.3%	1.83 (±0.48) [a]
	0.5%	1.97 (±1.36) [a]
	0.7%	2.39 (±1.06) [a]
150	0.3%	2.11 (±0.42) [a]
	0.5%	2.68 (±1.22) [a]
	0.7%	3.52 (±1.29) [a]
Control		1.83 (±0.64) [a]

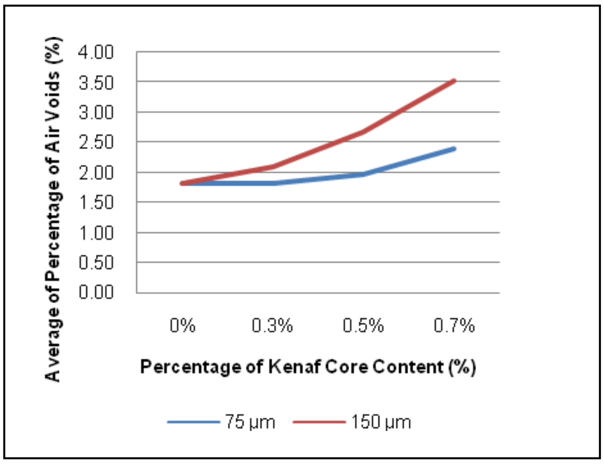
Note : The numbers in the brackets known as standard deviations.

[aa] Same letter shown no significant difference at $p \leq 0.05$.

[#] 3 replicates have been done for each of the average percentages of air voids (%) according to the specification of JKR in the range of 3.0% - 5.0%.

Control sample block and sample block which consists of 0.3% powder showed the lowest value of the average percentage of air voids which was about 1.83% when compared with other five sample blocks. Figure 2 shows the average percentage of air voids versus the percentage of kenaf core content.

Figure 2 : Graph showing the average percentage of air voids versus the percentage of kenaf core content.



Addition of kenaf core powder to the mixture showed an increasing pattern of the average percentage from 1.83% to 2.39%. Sample block which consists of 0.3% kenaf core content had increased about 30.6% compared to sample block which consists of 0.7%. However, result showed no significant differences at $p \leq 0.05$ among three different percentages of kenaf core content with the size of 75 µm added to the mixture as presented in Table 1. This can be seen in the sample block which contained kenaf core fibres with the size of 150 µm, average percentage of air voids increased with kenaf core content added to the mixture. Sample block with 0.3% of kenaf core fibres content differed by 66.82% significantly when compared with 0.7% content of kenaf core fibres. However, no changes in variation and no significant difference at $p \leq 0.05$ between the percentage of air voids and kenaf core content were shown in Table 1. Hence, there was a similarity between the average percentage of air voids and percentage of kenaf core contents.

No change in average percentage of air voids between control sample block and sample block of 0.3% kenaf core powder since the result of the average percentage of air voids for both sample blocks were the same which stated 1.83%. However, there was an increment in average percentage of air voids sharply by 92.35% between control sample block and sample block of 0.7% kenaf core fibres. The increment of the percentage of air voids is affected by the bonding between bitumen and aggregate due to air and moisture (Khadjijah, 2005).

From Table 1, all six sample blocks of 0.3% and 0.5% of kenaf core fibres showed that the average percentage of air voids were less than 3.0% thus not meeting the JKR specification. Khadjijah (2005) mentioned that lower value of average percentage of air voids will cause mixture to be more water-proof. Meanwhile, according to Akoto (2009), presence of small number of air voids could lead to bleeding which known as excess bitumen (excess asphalt), flushing, fatty surface which is the film of asphalt binder on the road surface. It usually creates shiny, glass-like reflecting surface that can become very sticky. Bleeding occurs when bitumen fills the aggregate voids during hot weather and then expands onto the road surface or when the road is subjected to traffic loading and lead to bitumen to squeeze out of the road surface where air voids percentage is reduced. Conversely, if it rains, the road surface becomes slippery which will increase the risk on the road (Vasudevan, 2004).

In this study, average percentage of air voids increased when increasing the percentage of kenaf core content. This might be due by the absorption characteristic of kenaf core materials which are able to fill the air voids between the aggreagtes. Increment in average percentage of air voids also caused by the increment of the percentage of voids in mineral aggregate, inconsistent temperature and cooking duration (Ting, 2009). At low temperature, viscosity of bitumen decreased which would affect the bonding between the aggregate and bitumen and as a result, more air voids were created.

Traffic loading

Road damage is caused by stress and tension during prolonged road use. Resilient modulus, M_r is one of the mechanical properties of the material which describes its stress-strain relationship under dynamic loading and specific physical conditions. Resilient modulus is defined as the ratio of the peak deviator stress (σ_d) to the recoverable axial strain (ε_r). The higher the resilient modulus value, the higher will be the tensile value which means the material is stronger and more stable. Therefore, sample block with higher resilient modulus value shows higher strength and stability. Table 2 showed the resilient modulus at 25°C with different traffic loadings.

For kenaf core powder as filler in HMA, the optimum percentage of kenaf core content was 0.3% which resulted in the highest resilient modulus value of 5115 MPa when 2000 N traffic loading was applied. Overall, resilient modulus decreased when kenaf core powder was added to the mixture, and when the traffic loading was applied on it was increased at 25°C as presented in Table 2. Figure 3 shows the resilient modulus against traffic loading at 25°C. The same sample block was tested with different traffic loadings.

By applying 1000 N traffic loading on the sample block at 25°C, resilient modulus of sample block with 0.5% kenaf core powder decreased by 16.57% compared to resilient modulus of sample block with 0.3% kenaf core powder. As for 2000 N traffic loading applied at 25°C, the resilient modulus was reduced by 22.49% and 26.41% when 3000 N traffic loading was applied on the sample block.

Based on Table 2, there was no significant difference at $p \leq 0.05$ in resilient modulus among the three different kenaf core powder contents added into the mixture when 1000 N traffic loading applied on the sample block. When 2000 N traffic loading was applied on the sample block at 25°C, the resilient modulus showed significant difference at $p \leq 0.05$, sample blocks with 0.3%, 0.5% and 0.7% of kenaf core powder were differed from one another. Similarly also can be seen for 3000 N traffic loading.

As for kenaf core fibres as filler in HMA, the optimum percentage among all kenaf core contents was 0.3% which obtained the highest resilient modulus value of 5255 MPa when 1000 N traffic loading was applied on the sample block. Result showed that the higher the resilient modulus value, the stronger and more stable was the sample block. Resilient modulus decreased when kenaf core fibres was added into the mixture with increasing traffic loading at 25°C. When 1000 N traffic loading applied on the sample block, resilient modulus of 0.5% kenaf core fibres sample block decreased by 26.9% compared to resilient modulus of 0.3% kenaf core fibres while resilient modulus of 0.7% kenaf core fibres decreased by 23.35% compared to resilient modulus of 0.5% kenaf core fibres content of the same size.

As when the traffic loading applied was increased to 2000N, resilient modulus of 0.5% kenaf core fibes content in the sample block with the size of 150 μm reduced by 11.04% compared to to resilient modulus of sample block of 0.3% kenaf core fibres content while resilient modulus of 0.7% kenaf core fibres content decreased by 14.57% compared to resilient modulus of 0.5% kenaf core fibes content of the same size. The same thing occurred when 3000 N traffic loading was applied on sample blocks at 25°C whereby resilient modulus of 0.5% kenaf core fibres reduced by 11.25% compared to to resilient modulus of sample block of 0.3% kenaf core fibres while resilient modulus of 0.7% kenaf core fibres decreased by 11.36% compared to resilient modulus of 0.5% kenaf core fibres.

Based on Table 2, there was no significant difference at $p \leq 0.05$ in resilient modulus between sample block of 0.5% and 0.7% kenaf core fibres when 1000 N traffic loading was applied at 25°C. Whereas, comparison in resilient modulus between sample block of 0.3% kenaf core fibres with sample block of 0.5% and 0.7% kenaf core fibres have showed significant difference at $p \leq 0.05$. For 2000 N traffic loading, comparison of resilient modulus between sample block of 0.3% and 0.5% kenaf core fibres showed no significant difference at $p \leq 0.05$. Similarly, there was no significant difference in resilient modulus between sample block of 0.5% and 0.7%. However, difference can be seen for 0.3% and 0.7%. When 3000N traffic loading was applied, comparison in resilient modulus made between sample blocks that consist of 0.3% kenaf core fibres with 0.5% as well as 0.5% kenaf core fibres with 0.7% showed no significant difference at $p \leq 0.05$ but otherwise for 0.3% compared with 0.7% % kenaf core fibres.

Generally, resilient modulus values decreased with increasing kenaf core contents and traffic loadings from 1000 N to 3000 N. According to Ting (2009), the addition of coir fibres content was able to reduce resilient modulus at 25°C. Resilient modulus decreased when traffic loading was increased from 1000 N to 4000 N. This can be explained by recoverable horizontal deformation rate which is greater than the rate of traffic loading imposed on the sample block (Ting, 2009). According to Mallick and El-Korchi (2009), the equation of resilient modulus, resilient modulus (M_r) is defined as stress (σ_d) divided by strain

(ε_r), and the resilient modulus value decreases due to stress (σ_d) increases. Therefore, the longer the use of roads by heavy vehicle, the faster will be the impact of road damage. However, the quantity of filler in bituminous mixture must be set correctly according to the calculation. If the filler content in bituminous mixture is insufficient, the road will become weak, and bitumen will melt easily in high temperature. Conversely, if the filler content is too high, this will cause the road become very brittle and prone to cracking even when traffic loading applies on it (Hatherlay and Leaver, 1967).

Conclusion

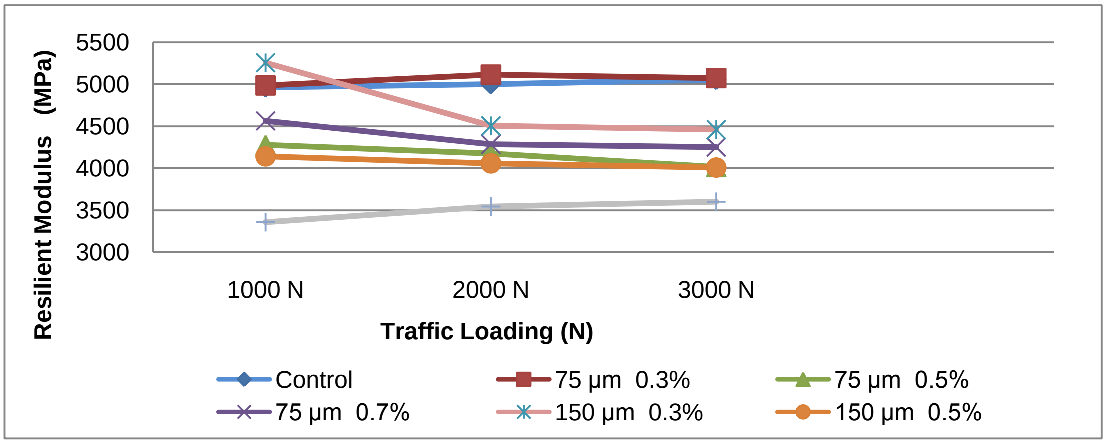
As a conclusion, optimum content for both kenaf core materials; powder and fibres, as alternative filler in HMA were 0.3% which resulted in the highest resilient modulus values. In addition, the more content of kenaf core were added into the mixture caused an increment in the average percentage of air voids which does not meet the JKR specification ranged from 3% to 5%. Besides that, the addition of kenaf core contents affected the bond between aggregate and bitumen which decreased the resilient modulus in the mixture when traffic loadings were increased at 25°C.

Table 2 : Resilient modulus at 25°C compared with percentage of kenaf core content.

		Resilient modulus (MPa) at 25°C with different traffic loadings					
Kenaf core size (µm)	Percentage of kenaf core content (%)	1000 N^{1}	2000 N^{1}	3000 N^{1}	1000 N^{2}	2000 N^{2}	3000 N^{2}
75	0.3	4987 ^{a} (±723.03)	5115 ^{a} (±558.42)	5074 ^{a} (±502.52)	6620	8170	7888
	0.5	4278 ^{a} (±756.05)	4176 ^{b} (±475.25)	4014 ^{b} (±418.84)	5931	5992	5797
	0.7	4564 ^{a} (±385.48)	4284 ^{b} (±460.94)	4251 ^{b} (±445.88)	ND	ND	ND
150	0.3	5255 ^{a} (±96.74)	4505 ^{a} (±421.69)	4459 ^{a} (±343.88)	ND	ND	ND
	0.5	4141 ^{b} (±199.57)	4057 ^{ab} (±316.69)	4008 ^{ab} (±363.67)	ND	ND	ND
	0.7	3357 ^{b} (±950.31)	3541 ^{b} (±746.64)	3599 ^{b} (±556.07)	ND	ND	ND
Control		4963	5001	5053	ND	ND	ND

Note : Number in bracket known as standard deviation.
ND = Not Done
[1] Current study
[2] Ting (2009) studied using coir fibre size of 40 mm in length.
[ab] Different letters in the column between percentage of kenaf core content shown significant difference at $p \leq 0.05$.

Figure 3 : Graph showing resilient modulus against various traffic loadings.



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