The Utilisation of Palm Kernel Shell as Partial Coarse Aggregate Replacement in Asphalt Mixture for Heavy Traffic Flow

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Abstract. Using Palm Kernel Shells (PKS) in road construction has a promising potential to minimise the agricultural waste that causes environmental problems and reduce overall road construction costs. This study uses varying percentages of 10, 20 and 30% PKS, an agricultural waste material, as a coarse aggregate replacement mixed with a 60/70 penetration grade bitumen. The sample compaction is 75 blows using the Marshall Method to simulate heavy traffic flow. This research evaluates the fatigue and rutting performances of the modified asphalt mixture through resilient modulus tests to determine the pavement performance in unaged, short-term and long-term aged conditions. The results revealed that the unaged PKS-10 has a 35% lower resilient modulus than PKS-0 after being subjected to varying pulse repetitions. The resilient modulus of the asphalt mixtures with higher PKS contents, PKS-20 and PKS-30, is about 55 and 65% lower than the PKS-0. The lower resilient modulus of all PKS asphalt mixtures indicates that PKS replacement is unsuitable for higher traffic volumes since it does not improve fatigue and rutting at intermediate and higher temperatures when subjected to ageing and different pulse repetitions. However, the lower ageing index than the control sample indicates that replacement with PKS delayed the ageing of the asphalt mixture exposed to heavy traffic flow and could extend the pavement service life.

1 Introduction

Pavement is a multi-layer system that distributes load over a large area to impart the pavement with the durability and ability to withstand traffic and environmental elements [1]. The hard surface of the pavement is the paved area covered with the material produced by mixing aggregates with bitumen as a binder and then compacted the mixture at a specific temperature. The critical factor in road pavement construction is the materials. Failure to use the materials prescribed for standard road pavement construction can cause pavement distress

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upon exposure to high stress, which results in failures and defects. Even though pavement deterioration is inevitable, it is possible to reduce or slow down the rate of deterioration.

However, there are several hindrances in achieving this goal. The expanding global economy and the strive for development have increased the price of the materials used in pavement construction. For example, the gradual and consistent increase in bitumen price contributes to the overall pavement construction cost, forcing developers to allocate higher budgets for pavement construction. Additionally, the exponentially increasing traffic volume and changing environment adversely affect pavement performance and cause pavement failures. The high amounts of agricultural waste generated in Malaysia cause environmental pollution and waste disposal issues.

Given the graveness of these issues, the road paving industry has taken the initiative to enhance asphalt mixture performance using alternative and sustainable materials that satisfy the requirements for pavement performance. The selected alternative replacement materials must be technically, commercially and environmentally feasible to be sustainable [2]. The world is living on a garbage time bomb, where agricultural and industrial wastes contribute to waste management and environmental issues [3]. Using agriculture and industrial wastes as supplementary materials could have practical and economic benefits in the road construction industry. Generally, wastes have little commercial value and are available at almost no cost, and since they are readily available locally, the transportation cost is minimal. Those in the road construction sector can reduce construction costs and environmental degradation by exploring novel initiatives.

Therefore, researchers have attempted to use waste material such as palm kernel shells (PKS) as aggregate replacements to enhance asphalt mixture performance [2-5]. Findings from previous study showed up to 10% PKS replacement increased the resistance towards fatigue and rutting failures for medium traffic flow [6]. Researchers have also modified bitumen with recycled bitumens, bio-oils and warm mix asphalts [7]. The objective of pavement modifications has always been to improve the performance of the pavement while minimising defects such as as fatigue, rutting, and cracking. Therefore, the priority of pavement technologists and researchers has always been to construct pavements with long lifespans for road users which is sustainable and eco-friendly.

Therefore, this study uses a waste material, PKS in asphalt mixtures to determine the fatigue and rutting performance of aged PKS asphalt mixtures under heavy traffic loads by subjecting the mixtures to different pulse loading. It also analyses the ageing index (AI) of PKS asphalt mixtures to determine if the PKS replacement delays the oxidation of the modified asphalt mixture.

2 Materials and Method

2.1 Materials

This study follows the recommendation of a previous study [8] to use aggregates from a single source to ensure consistent quality and attributes throughout the laboratory work and the guidelines in ASTM 2419. It uses 60/70 penetration grade bitumen, and Bio-Eneco Sdn Bhd supplied the PKS (Fig. 1) used as a partial coarse aggregate replacement in the asphalt mixtures in varying percentages of 10%, 20% and 30%. The PKS used as the partial coarse aggregate replacement has similar properties as the aggregates and passes sieve no. 4 (5mm-14mm).

Fig. 1. Palm Kernel Shells

2.2 Sample Preparation

The optimum bitumen content for each asphalt mixture was adopted from [5]. The mix design for the aggregate and bitumen contents was determined by the Marshall Test and volumetric analysis. The JKR/SPJ/2008-S4 specifies a constant mixing temperature of 160°C. The samples were compacted into the mould using a Marshall compactor machine with 75 blows to simulate a heavy traffic flow. Each face of the sample was compacted before extruding it from the mould. Fig. 2 shows the samples before conducting the tests.

Fig. 2. PKS asphalt mixture sample

2.3 Short-term and long-term ageing

Short-term ageing (STA) is a process that simulates the effects of plant mixing and construction at the site on asphalt mixture. The asphalt mixture's high temperature during mixing can affect its performance properties [9]. The loose mixture was immediately placed in a pan, evenly spread out and put in a 135 °C oven for four hours to condition the samples for STA and stirred every 60 minutes to ensure uniform conditioning of the mixtures. The mixture was compacted immediately after conditioning. Long-term ageing (LTA) is a process that simulates the pavement condition after ten years of service life. The process for LTA continued after completing the STA. The compacted STA samples were aged in a forced draft oven for five days at 85 °C to simulate the LTA process.

2.4 Resilient Modulus test

The resilient modulus test was conducted to compute the vertical strain at the top of the subgrade layer and the horizontal strain at the bottom of the asphalt layer. The selected temperature (25°C) was based on the mixture's resistance to fatigue, while the 40°C was based on the mixture's resistance to rutting or permanent deformation [10]. The specimens were kept for two hours before being tested using a Universal Testing Machine. The standard testing parameters follow the ASTM D4123 specifications.

2.5 Ageing Index

The ageing index (AI) was calculated to determine the effect of PKS in delaying the ageing of the modified asphalt mixture using Eq 1, where Mr (unaged) is the value of unaged resilient modulus and Mr (aged) is the value of aged resilient modulus. Higher AI values indicate that the PKS did not contribute to delaying the ageing process [6].

$$\textit{Ageing Index (AI)} = Mr_{(aged)}/Mr_{(unaged)} \tag{1}$$

3 Results and discussion

3.1 Fatigue performance at 25 °C

Figs. 3, 4 and 5 show the resilient modulus results for the unaged samples, aged samples and different pulse repetitions. The resilient modulus decreased linearly with higher PKS percentages. Fig. 3 shows that compared to PKS-0, the resilient modulus for the unaged PKS-10 sample decreased by approximately 35% after being subjected to pulse repetitions of 1000, 2000 and 3000 ms. Increasing the PKS percentage to 20% and 30% (PKS-20 and PKS-30) resulted in 55% and 65% lower resilient modulus compared to PKS-0, indicating that the high water content of the PKS affected the asphalt mixtures' resistance against fatigue failure [6]. The water ingress into the asphalt mixtures accelerated ageing processes, such as oxidation and stripping of the binder-aggregate bonds, which reduced the resilient modulus due to the diminished structural integrity. The aged STA and LTA showed a similar resilient modulus trend at the same temperature, as shown in Figs. 4 and 5. Compared to PKS-0, the 27%, 54%, and 61% resilient modulus of PKS-10, PKS-20, and PKS-30 are lower at different pulse loading, as shown in Fig. 4. LTA resulted in a comparable lower resilient modulus of 27%, 45% and 62%, as shown in Fig. 5.

Compared to PKS-0, the aged PKS asphalt mixture samples had a higher resilient modulus at all pulse repetitions. Ageing generally resulted in a higher resilient modulus due to the higher stiffness and lower flexibility caused by various factors, such as oxidation, moisture damage and temperature [8]. The changes in the resilient modulus could have significantly affected the overall performance and durability of asphalt pavements over their service life. This result concurred with the study by [11], where the resilient modulus increased after the STA of the asphalt mixture.

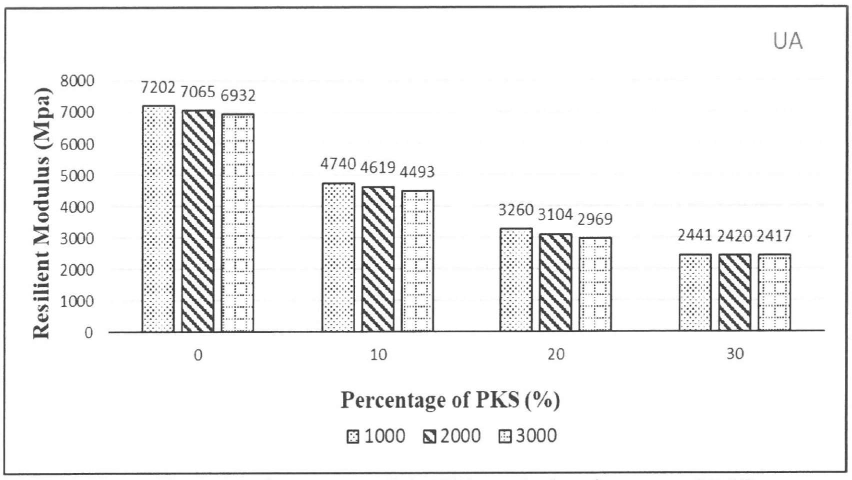

Fig. 3. Fatigue performance of the UA asphalt mixture at 25 °C

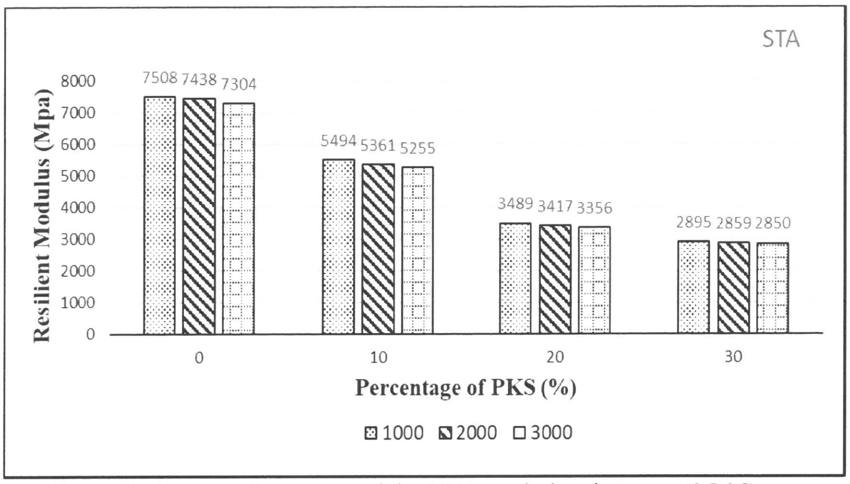

Fig. 4. Fatigue performance of the STA asphalt mixture at 25 °C

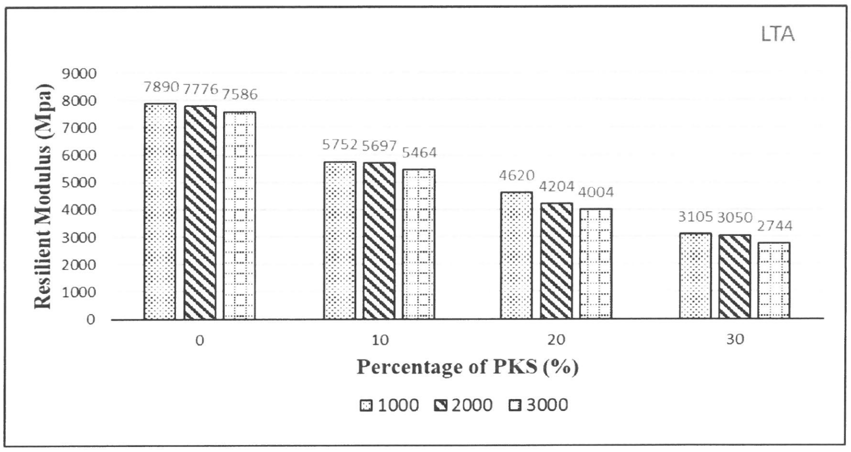

Fig. 5. Fatigue performance of the LTA asphalt mixture at 25 °C

3.2 Rutting performance at 40 °C

Increasing the temperature to 40 °C significantly reduced the resilient modulus of all asphalt mixture samples. Figs. 6, 7 and 8 show the declining stiffness of the unaged and aged asphalt mixtures at different pulse repetitions and higher temperatures. A comparison of the PKS samples showed that the UA, STA and LTA PKS-10 had the highest resilient modulus of 796, 877 and 1017 Mpa at 1000 ms pulse repetition. Increasing the PKS percentage lowered the resilient modulus of PKS-30 and reduced its resistance against rutting failure. The linear trend in reduced fatigue performance at an intermediate temperature was unsurprising since ageing gradually decreased the material properties of the asphalt mixtures, thus lowering their resilient modulus as they become more susceptible to fatigue and permanent deformation. This result is consistent with a previous study by [7], which found that the resilient modulus of the asphalt mixture was lower at higher temperatures. However, the higher stiffness after ageing increased the resilient modulus of PKS-10 by 81 Mpa from UA to STA and 140 Mpa from STA to LTA at 1000ms pulse repetitions. This pattern is similar for all conditions, indicating that ageing stiffened the asphalt mixture.

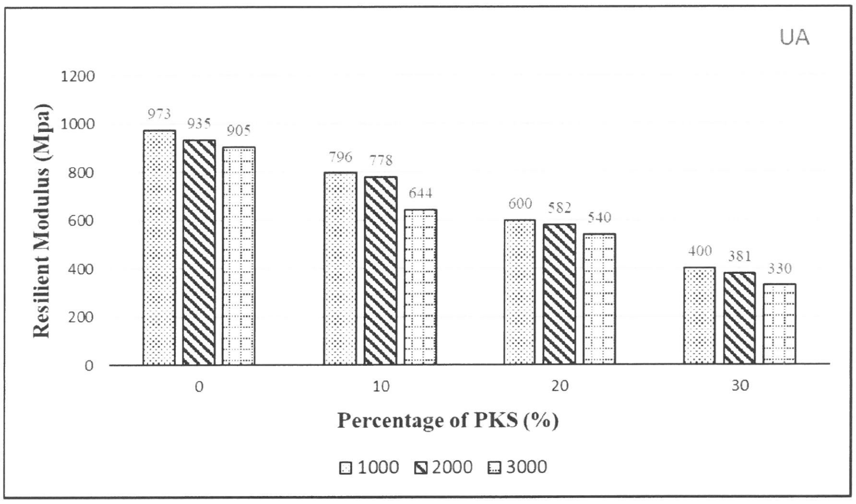

Fig. 6. Rutting performance of the UA asphalt mixture at 40 °C

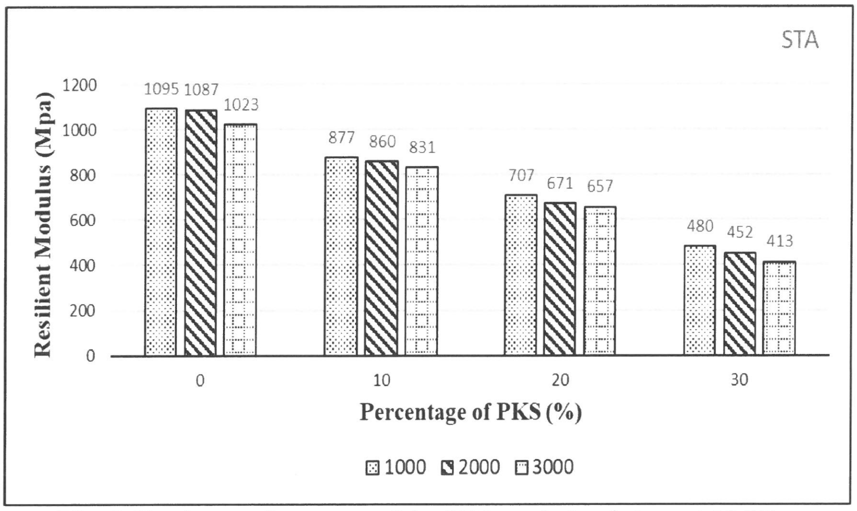

Fig. 7. Rutting performance of the STA asphalt mixture at 40 °C

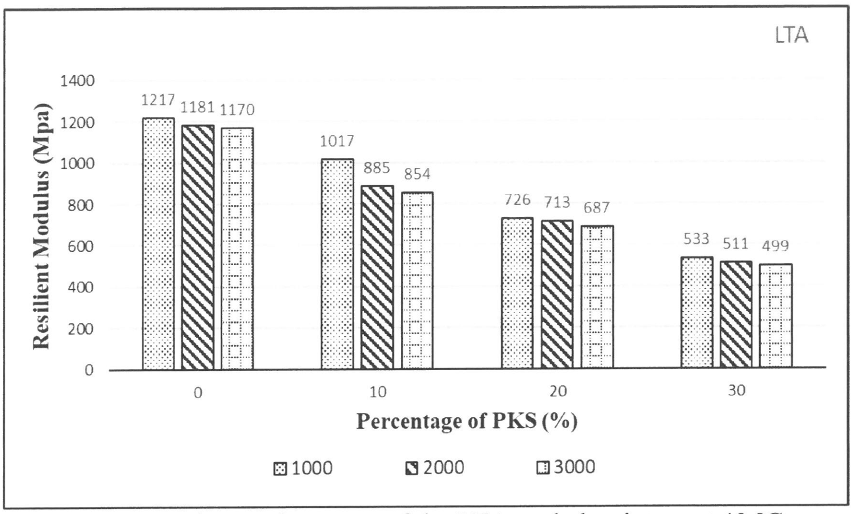

Fig. 8. Rutting performance of the LTA asphalt mixture at 40 °C

3.3 Ageing index of PKS asphalt mixture

Tables 1 and 2 present the AI values for the STA and LTA at intermediate and high temperatures and different pulse loadings. PKS-10 and PKS-20 had lower AI values than PKS-0. The AI of PKS-30 remained considerably higher, proving that using PKS delayed the ageing process of the asphalt mixture by lowering the AI values for the asphalt mixtures with 10 and 20% PKS replacement under heavy traffic loads. The result is similar to a study by [6], which investigated the AI values of modified PKS under medium traffic flow.

Table 1. Ageing index at 25 °C

% PKS	STA				LTA			
	Ageing Index			Remarks	Ageing Index			Remarks
0	1.04	1.04	1.04	Control	1.10	1.10	1.09	Control
10	1.02	1.02	1.02	Lower	1.05	1.05	1.07	Lower
20	1.02	1.01	1.00	Lower	1.02	1.02	1.02	Lower
30	1.10	1.09	1.09	Higher	1.27	1.27	1.25	Higher

Table 2. Ageing index at 40 °C

% PKS	STA				LTA			
	Ageing Index			Remarks	Ageing Index			Remarks
0	1.13	1.16	1.13	Control	1.10	1.10	1.12	Control
10	1.10	1.10	1.10	Lower	1.07	1.09	1.10	Lower
20	1.07	1.07	1.05	Lower	1.09	1.09	1.09	Lower
30	1.20	1.19	1.22	Higher	1.33	1.34	1.33	Higher

4 Conclusion

This study evaluated the performance of the PKS asphalt mixture subjected to ageing and heavy traffic loads. The pavement performance was based on the resilient modulus test conducted at 25 and 40 °C to represent intermediate and high temperatures. The result of the resilient modulus test revealed that PKS is not a suitable replacement for pavements subjected to heavy traffic flow (75blows) because their low resilient modulus indicates that they were susceptible to rutting failure. The AI evaluation revealed that the PKS delayed the ageing of PKS asphalt mixtures, as indicated by the lower AI values of the PKS-10 and PKS-20. The results were similar for the asphalt mixtures exposed to 25 and 40°C at different pulse repetitions. The delayed ageing might have delayed the need for major rehabilitation or replacement and extended the pavement's service life. In conclusion, PKS asphalt mixture is recommended for use on pavement designed for low and medium traffic volumes only. The permanent deformation and moisture susceptibility of the PKS asphalt mixture may be assessed in future research to determine its suitability for usage in road construction.

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