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# Bio-Asphalt Concrete: From Waste Product to Green Aggregate Replacement

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## ABSTRACT

Malaysia has over 5 million hectares of land planted with palm oil, divided almost equally between peninsula Malaysia and East Malaysia. This paper presents a laboratory evaluation of the performance of the waste product palm kernel shell (PKS) in creating plant-based asphalt concrete (bio-asphalt concrete). PKS aggregate partially replaced granite aggregate in preparing the mixes (10%, 30%, and 100%) in the range of 5mm-14mm in ACW 14 mixed with 5% to 7% of bitumen content. 35 blows and 50 blows compaction of mixes was used to evaluate the potential of palm kernel shells in the preparation of bitumen to deal with light to medium traffic. Results showed that PKS aggregate can be used up to 30% PKS replacement for the light traffic design and only 10% PKS replacement was potential to be used in medium traffic design.

*Keywords:* Bio-asphalt concrete, green aggregate replacement, oil palm, palm kernel shell

## INTRODUCTION

The production of flexible pavement relies on the availability of mineral aggregate (stone) the most important ingredient behind the rising cost of pavement structure. This has led to interest in finding suitable replacement material as a substitute for natural stone. Using waste materials as an alternative can help in conserving natural resources, disposal of waste materials, and making land available for other economic benefit (Sherwood, 1995). Wastes generally have no commercial value and does not compromise product performance (Zemke and Woods, 2009). Indonesia is the largest palm oil producing country in the world followed by Malaysia in second place (MPOB, 2013).

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Empty fruit bunches (EFB), palm kernel shells (PKS) or oil palm shells (OPS), pericarp and palm oil mill effluent (POME) are palm oil by-products which can be used in the construction industry, such as to replace natural stone in asphalt concrete mixtures.

Ndoke (2006) investigated the suitability of palm kernel shells as a partial replacement for coarse aggregates in asphalt concrete, and found its suitability as a partial replacement for coarse aggregate up to 10% for heavily trafficked roads and 50% for light trafficked roads. Lee (2012) investigated the potential of raw oil palm shell (5mm) as an aggregate replacement in high volume road design, and concluded that palm kernel shells (5% of 5 mm) as the coarse replacement to be unsuitable for high volume road design. This study investigates the replacement of conventional coarse aggregates by palm kernel shells on stability, flow and the volumetric properties of pavement and low to medium traffic conditions.

## MATERIALS AND METHODS

### Materials Used

The raw material used for the study was sourced locally, and added to bitumen as a binder, fine aggregate, palm kernel shell (PKS) as coarse aggregates and ordinary Portland cement (OPC) as a mineral filler. The specific gravity of coarse aggregate, fine aggregate, palm kernel shell and OPS are 2.57, 2.26, 0.90 and 3.13 respectively. The bitumen used was 85.5 mm penetration grade and having softening point of 42.25°C.

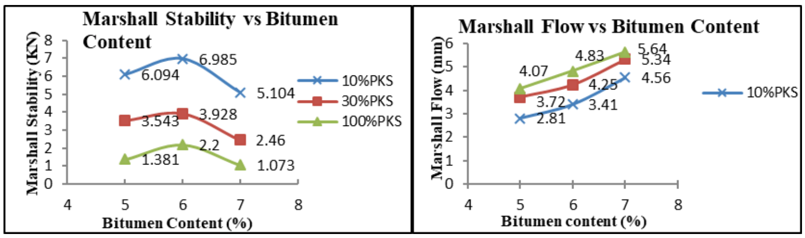
### Methodology

Results from a trial and error method of blending aggregate revealed 53% of coarse-grained sizes, 35% of the fine-grained and mineral fine of 12% in the mixture. These material proportions were n mixed with bitumen content at range 5%-7% with temperature between 175-190oC and compacted in the mould for the Marshall Stability tests. Two different number of compaction were applied, that is 50 blows and 35 blows. Palm kernel shells were added at 10%, 30% and 100% by weight of total coarse aggregate (5mm-14mm) still maintaining the percentages so that the palm kernel shell acts as a replacement for the coarse aggregate. Three samples were prepared and Marshall Stability tests were carried out on the samples as per shown below.

## RESULTS AND DISCUSSION

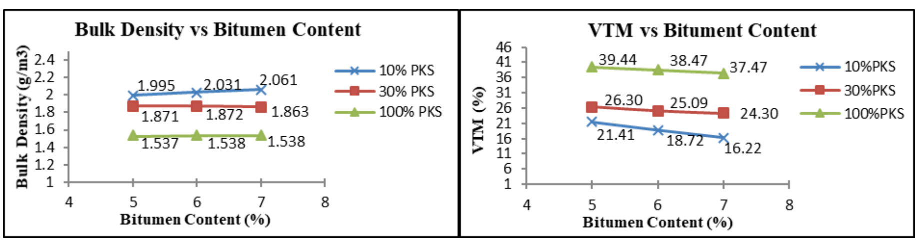
### Palm Kernel Shell Asphalt Mix Design Result

### 50 Blows of Compaction (Medium Traffic Design)



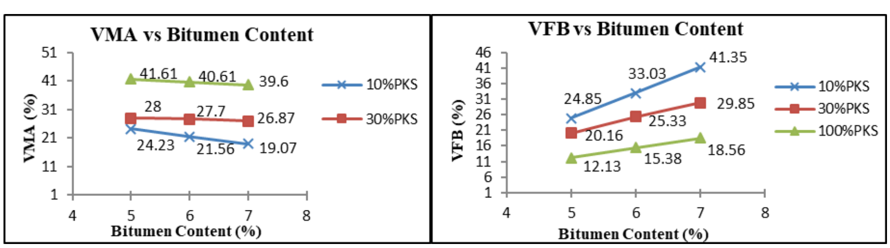

(a) (b)

*Figure 1.* (a) Marshall Stability curves for modified mixes; and (b) Marshall flow curves for modified mixes




(a) (b)

*Figure 2.* (a) Bulk density curves for modified mixes; and (b) Voids in Total Mix percent curves for modified mixes




(a) (b)

*Figure 3.* (a) Voids in Minerals Aggregates percent curves for modified; and (b) Voids Filled with Bitumen percent curves for modified mixes

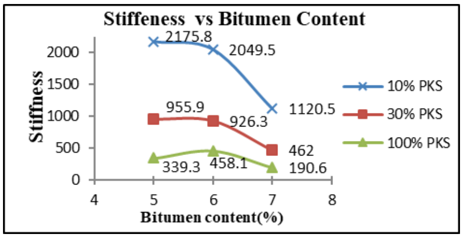



*Figure 4.* Stiffness curves for modified mixes

## Marshall Stability

The results shown in Figure 1(a) represent the stability of asphalt specimens at various percentages palm kernel shell (PKS) replacement. All of the line graphs had similar appearances as a smooth curve. Highest stability was reached 6.985 KN at 10% PKS replacement and lowest stability at 2.2 KN when replaced with 100% of PKS. This shows that a reduction in the percentage of up to almost 50%. When the course was reduced and palm kernel shells added, the Marshall stability was also reduced.

## Marshall Flow

Based on Figure 1(b), the highest flow values reached 100% PKS replacement is 4.07mm at 7% bitumen content while the second highest of flow was observed at 30% PKS replacement and almost similar value at 7% bitumen content with 100% PKS replacement with different of 0.03mm. The lowest flow was observed at 10% PKS replacement with 5% percentage of bitumen content, indicating the increased percentage of PKS in the mixture of the specimen tends to reduce the stability of the specimen. A reduction of flow implies better strength of the mixed specimen.

## Bulk Density

Figure 2(a) represents the computed test results obtained from bulk density of PKS asphalt specimens at various percentage of PKS replacement and mixed at specified bitumen content percentages. The specific gravity varies due to the aggregate composition and specific gravity of the PKS does not place it in the category of common rock groups whose gravities range from 2.62-3.00 (Nevile, 1995). Hence, the lowest bulk density is obtained when 100% of PKS replaced at the coarse aggregate compared to the 10% of PKS replacement which had the highest bulk density due to the normal coarse aggregate partially exist in the mix.

## Voids in Total Mix (VTM)

Based on the graph in Figure 2(b), 100% PKS mixtures achieved the highest VTM percent of 39.44% at 5% bitumen contents and decreased as the bitumen content was increased. The PKS replacement at the coarse aggregate will result in higher VTM which leads to the permeability of water resulting premature hardening of the asphalt pavement. High percent VTM indicates the compacted mixture with PKS replacement has a high tendency not occupied by aggregate or asphalt. Besides due to the density and voids are directly related, the lower the bulk specific gravity or density, the higher the percentage of voids in the mix

### Voids in Mineral Aggregate (VMA)

Figure 3(a) shows increasing bitumen content will reduce the percent of VMA as the aggregate tends to absorb more asphalt binder and reduced the volume of the asphalt not absorbed into the aggregate. The highest percent of VMA is 41.61% at 5% bitumen content for 100% PKS followed by 26.87% at 7% bitumen content for 30% PKS and lastly, the lowest VMA is 19.07% at 7% bitumen content for 10% PKS. This indicates the increasing PKS will result in a high percent of VMA due to PKS aggregate shape being is more angular.

### Voids Filled with Bitumen (VFB)

Figure 3(b), shows 10% PKS has the highest percent of VFB compared to 30% PKS and 100% PKS. This indicates as more PKS is introduced to the specimen, the percent of VFB decreases, and where low percent VFB indicates the modified bitumen mix resulting thin film of binder due to PKS aggregate reveal higher in binder absorption compared to normal coarse aggregates.

### Stiffness

Figure 4 shows the relationship between stiffness and bitumen content. The stiffness for 10% PKS replacement was greater than the 30% PKS replacement and 100% PKS replacement. The decrease in Marshall Stability value indicates the specimens are less stiff. The low value of stiffness is due to the lack of a proper degree of both internal friction and cohesion of the modified bitumen mix which can result in the aggregate particles being moved past each other by the forces exerted.

### 35 Blows of Compaction (Low Traffic Design)

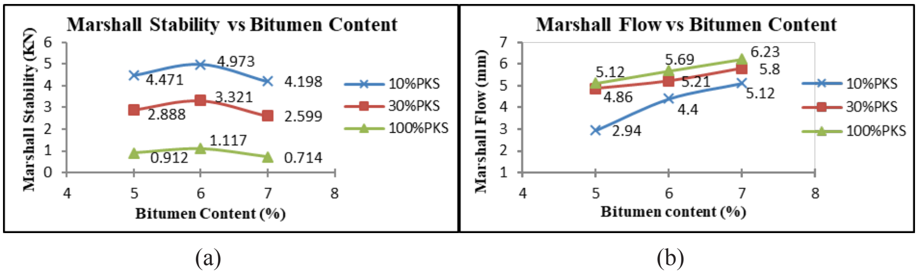
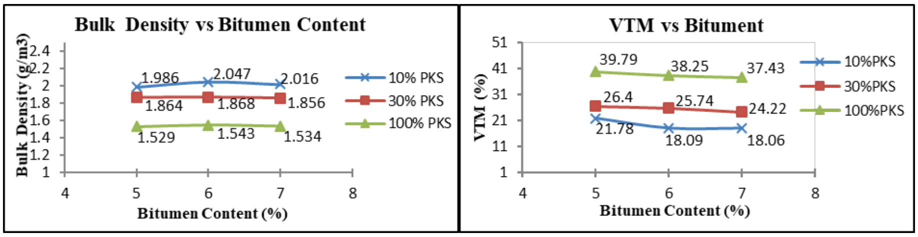
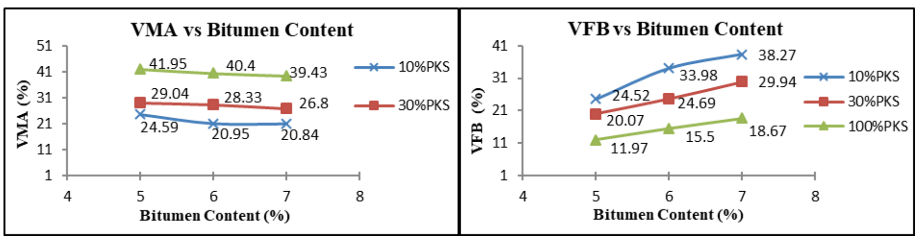



*Figure 5.* (a) Marshall stability curves for modified mixes; and (b) Marshall flow curves for modified mixes




(a) (b)

*Figure 6.* (a) Bulk Density curves for modified mixes; and (b) Voids in Total Mix percent curves for modified mixes




(a) (b)

*Figure 7.* (a) Voids in Minerals Aggregates percent curves for modified; and (b) Voids Filled with Bitumen percent curves for modified mixes

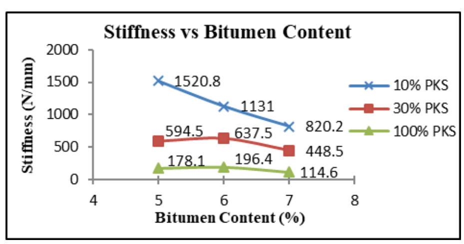



*Figure 8.* Stiffness curves for modified mixes

## Marshall Stability

Figure 5(a) shows the graph of Marshall Stability with 35 numbers of blows. The pattern of the graph is similar with Figure 1 and the reduction of Marshall Stability value is due to the low percentage of normal aggregate used. At 35 blows of compaction a low value of Marshall Stability was recorded since particles in the mixture are not interlocked as closely as when the specimens are subjected to 50 blows of compaction. Blades and Kearney (2004) mentioned that compaction provides adequate lubrication for aggregates to stick each other, and improves quality.

## Marshall Flow

Figure 5(b) presents Marshall Flow values based on bitumen content. It is clear that flow values of different percentage PKS replacement increases as the bitumen content increases, and similar to asphalt concrete mixture. The result indicates the replacement of PKS at coarse aggregate gives higher values of Marshall Flow due to the low interlocking and friction resistance of PKS aggregate.

## Bulk Density

Figure 6(a) shows the bulk density for various percentages of PKS as a function of bitumen content. It was noted bulk density curves for all percentage PKS replacement shows the same trend as that of hot mixes prepared with various bitumen contents. The graph also shows that for the same bitumen content, the bulk density for 10% PKS replacement is higher than that of 30% PKS replacement and 100% PKS replacement. This reduction in values of bulk density for PKS asphalt specimen results from the low specific gravity of PKS.

## Voids in the Total Mix (VTM)

Figure 6(b) shows the relationship between the percent of voids in the total mix and bitumen content for different percentage of PKS replacement. It can be noticed that the percentage of VTM decreases with an increase in the bitumen content. So too, the percentage of VTM for 100% PKS replacement is higher than that of 10% PKS replacement and 30% replacement for various bitumen content. The surface texture of PKS is rough and different from normal coarse aggregate. According to Chadbourn (2000), aggregates with rough surfaces have a high level of internal frictions, higher air voids s and higher VMA. Hence, the greater the amount of PKS added to a specimen the higher the percentage of VTM.

## Voids in Mineral Aggregate (VMA)

Figure 7(a) shows the percentage of VMA for various quantities of PKS and bitumen content. It indicates that percentage of VMA for different proportions of PKS replacement decreased with increasing percent of bitumen content and rising when PKS added to the specimen is increased. This is due to the increased number of sharp edges and fractured faces as angularity of the PKS aggregate creates more void space during compaction.

## Voids Filled with Bitumen (VFB)

Figure 7(b) shows the percentage of VFB rises with an increase in bitumen content. The graph above indicates that for the same bitumen content, percentage of VFB for 10% PKS replacement is higher than that of 30% and 100% PKS replacement.

## Stiffness

Figure 8 shows the relationship between stiffness and bitumen content. The graph shows s stiffness for 10% PKS replacement was greater than 30% and 100% PKS replacement. The reduction in the Marshall Stability value with the increase of Marshall Flow value will indicate lower stiffness of the specimens. Additionally, the stiffness of asphalt improved due to higher degree of compaction.

## Marshall Result and Specifications

Table 1 until Table 2 shows the Marshall result and specification based on JKR/SPJ/rev 2008 and Asphalt Institute standard, 1979. The results obtained are based on the optimum bitumen content of the mix.

Table 1
*50 blows of compaction*

| | Value at OBC | | | Specifications | |
|---|---|---|---|---|---|
| | 10% Replacement | 30% Replacement | 100% Replacement | JKR/SPJ/rev 2008 | Asphalt Institute,1979 |
| | | | | Heavy Traffic Volume Design | Medium Traffic Design |
| Stability | 5.57 KN | 3.19 KN | 1.35 KN | >8000 N | 3336 N (minimum) |
| Flow | 4.33 mm | 4.80 mm | 5.44 mm | 2.0 mm - 4.0 mm | 2.0 mm - 4.5 mm |
| Stiffness | 1351 N/mm | 692 N/mm | 257 N/mm | >2000N/mm | - |
| Air Voids in Total Mix (VTM) | 17% | 25% | 38% | 3.0% - 5.0% | 3.0% - 5.0% |
| Voids in Aggregate Filled with bitumen (VFB) | 39% | 28% | 18% | 70% - 80% | - |
| Voids in Mineral Aggregate (VMA) | 38% | 27% | 40% | - | 14.8% |

Table 2
*35 blows of compaction*

| | Value at OBC | | | Specifications | |
|---|---|---|---|---|---|
| | 10% Replacement | 30% Replacement | 100% Replacement | JKR/SPJ/rev 2008 | Asphalt Institute,1979 |
| | | | | Heavy Traffic Volume Design | Medium Traffic Design |
| Stability | 4.59 KN | 3.14 KN | 0.92 KN | >8000 N | 2224 N (minimum) |
| Flow | 4.76 mm | 5.35 mm | 5.96 mm | 2.0 mm - 4.0 mm | 2.0 mm – 5.0 mm |
| Stiffness | 974 N/mm | 590 N/mm | 155 N/mm | >2000N/mm | - |
| Air Voids in Total Mix (VTM) | 18% | 25% | 38% | 3.0% - 5.0% | 3.0% - 5.0% |
| Voids in Aggregate Filled with bitumen (VFB) | 36% | 26% | 17% | 70% - 80% | - |
| Voids in Mineral Aggregate (VMA) | 20.4% | 28% | 40.2% | - | 14.8% |

Generally, 10%, 30% and 100% replacement of PKS in ACW 14 does not satisfy the requirement needed by JKR standard. Data shown in Table 1 and table 2 is based on the standard requirement stated in Asphalt Institute, 1979. Replacement of 10% of PKS in ACW 14 has potential for medium traffic design and 10% and 30% for light traffic design. Percent of VTM and VMA does not meet the requirement.

## CONCLUSION

Data from this research found that palm kernel shell used as a coarse aggregate replacement has potential for use in both medium and light traffic design. Based on the optimum bitumen content, 10% PKS and 30% PKS can be used to replace coarse aggregate in HMA for light traffic design and only 10% PKS for medium traffic design. The performance on modified bitumen mix is not 100% perform well as several parameters did not satisfy the specification.

## ACKNOWLEDGEMENTS

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