British Journal of Applied Science & Technology
10(3): 1-13, 2015, Article no.BJAST.18785
ISSN: 2231-0843

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Investigation of the Effects of Partial Replacement of Coarse Aggregate with Graded Palm Kernel Shell in Asphaltic Binder Course

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Authors' contributions

This work was carried out in collaboration between both authors. Both authors read and approved the final manuscript.

Article Information

DOI: 10.9734/BJAST/2015/18785
Editor(s):
(1) Jakub Kostecki, Department of Civil and Environmental Engineering, University of Zielona Góra, Poland.
Reviewers:
(1) Alonge O. Richard, Universiti Sains Malaysia, Penang, Malaysia.
(2) Mehmedi Vehbi GÖKÇE, Department of Architecture, Niğde University, Turkey.
Complete Peer review History: http://sciencedomain.org/review-history/9891

Short Research Article

Received 9th May 2015
Accepted 5th June 2015
Published 20th June 2015

ABSTRACT

This work investigated the effects of incorporating palm kernel shells (PKS) as partial replacement of coarse aggregates in hot mix asphaltic binder course. All the volumetric properties and the physical properties of the asphalt mixture were evaluated in order to determine the potential of PKS in the production of binder course for medium-trafficked roads. Percentages of PKS content rates used were 0%, 30%, 50%, 70% and 100% by weight of total coarse aggregate size of 4-8 mm. Specifically, 15 samples for control mix and 60 samples for the PKS proportions of compacted asphaltic mixture were prepared by using Marshall mixing procedure. The samples were prepared by varying bitumen content from 4.5% to 6.5% and tested using the Marshall Method.
The results of control samples and PKS-incorporated samples showed effective PKS content at 50% replacement having 5.7% optimum bitumen content. Overall, it is established that PKS is a viable agriculture waste product that can be used as coarse aggregates at a specific percentage in the production of asphaltic binder course for light to medium-trafficked roads.

Keywords: Palm kernel shells; coarse aggregate; binder course; volumetric properties; Marshall stability; flow.

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1. INTRODUCTION

The road construction industry depends majorly on conventional materials such as; asphalt cement, granite, sand and filler for the production of asphalt concrete. The high and increasing cost of these materials have greatly hindered the development of road pavement facilities in developing countries. The need for engineering consideration of the use of cheaper and locally available materials to reduce the construction cost for sustainable development cannot be over-emphasized. In recent years, natural resources have been considerably reduced due to growth of mining industries and increase in the usage of mined materials [1]. Aggregate is a mined material which is being used in civil structures such as buildings, dams, bridges, and pavements. The amount of aggregate in asphalt paving mixtures is generally 90 to 95 percent by weight or 75 to 85 percent by volume and almost 12,500 tons of aggregates are being consumed for each kilometer of flexible pavements [2]. These amounts of aggregates are largely obtained from natural resourses which are detrimental to the environment as a result of mining activities. Researchers in material science and engineering are committed to having local materials to partially or fully replace these costly conventional materials [3]. Some of these wastes include sawdust, pulverized fuel ash, slag and fly ash which are produced from milling stations, thermal power stations, and waste treatment plants [4]. In addition, other materials explored in partial replacement for aggregates include cow bone ash, palm kernel shells, fly-ash, rice husk, and rice straw as pozzolanic materials. The use of coconut husk ash, corn cob ash and peanut shell ash as cement replacement have also been investigated [5].

However, the use of waste products such as furnace slag, steel slag, fly ash, palm kernel shell etc. as partial or total replacement of aggregate and filler in the production of asphalt concrete mixes in surface bound layers should be considered as alternative which is now coming up as a new development for economical sustainable infrastructure like road construction. This creates a demand for evaluation of the performance of those waste products in the asphalt mixtures. Using agricultural waste materials (PKS, here) as a partial replacement of asphalt aggregate mixture is one of the vital areas of research.

Mohammed et al. [6] stated that about 1.5 million tons of palm kernel shells are produced per annum in Nigeria. This huge amount of waste creates significant amount of problems with respect to handling and storage, which are important both from the economical as well as environmental point of view.

Few research works have been conducted to determine the effects of the PKS in bituminous mixture as a partial replacement for both coarse and fine aggregate, majorly on dense-graded asphalt where analyses were much on the physical properties (stability and flow) with little or no consideration on the volumetric properties (percent air voids, voids in mineral aggregate, voids filled with bitumen). On the other hand, many studies have been carried out on the utilization of PKS in the production of structural concrete.

Ndoke, [7] investigated the potentials of palm kernel shells as coarse aggregates in road binder course with emphasis on strength of the asphalt concrete as given by the Marshal Stability and flow values. He observed that Palm Kernel Shells could be used as partial replacement for coarse aggregate up to 10% for heavily trafficked roads and 50% for light trafficked roads. But there were some shortcomings that make the report not comprehensive enough, e.g. the graphs showing the trend of the partial replacement results, non-inclusion of the volumetric properties of the manufactured asphalt concrete, etc.

Mohammed et al. [6] presented a paper on the preliminary assessment of some properties of asphaltic concrete, with partial replacement of fine aggregate (sand) with crushed palm kernel shell. The preliminary investigation showed that replacement of some proportions of fine aggregate (sand) with crushed palm kernel shells is capable of imparting positively on some properties of asphaltic concrete. In addition, the study was able to establish that not only was uniform grain size distribution achievable from crushed palm kernel shell, the 10% and 50 % by weight replacement of fine aggregate with crushed palm kernel, satisfactorily supported the requirements for asphaltic concrete.

Yusuf and Jimoh, [8] worked on the appropriateness of the various nominal mixes of the ‘palm kernel shell concrete’ as rigid pavement. They evaluated the mixes accordingly at both fresh and matured ages with corresponding costs. They reported that the Nigerian PKS satisfies the density criterion for normal concrete and lightweight concrete in all respects while the palm kernel shell concrete at nominal mixes of 1:1½:3 and 1:1:2 satisfied the specifications for rigid pavement.

Daniel and Emmanuel, [9] investigated on the effects of replacing crushed granite with palm kernel shells on the strength, density and workability of structural concrete with cost implications.

2. MATERIALS AND METHODS

The conventional materials which formed the asphalt concrete were: stone dust (0-5 mm), river sand (0-4 mm) and crushed stone of sizes: 4-8 mm, 8-16 mm and 16-24 mm. These were obtained from Julius Berger Construction Company. The bitumen (60/70 pen.) was also obtained from Julius Berger Construction Company laboratory.

The palm kernel shells were obtained from Ikole Ekiti south west of Nigeria (Coordinates: 7.7833ºN, 5.5167ºE).

The PKS and aggregates used were tested for their specific gravities (Table 1). Dense mix design incorporating penetration grade 60/70 bitumen (Table 3) was used to produce the specimens for testing. Specified percentage proportions of the samples used for combined gradation in the production of asphalt concrete for binder course was carried out as follows: 32% stone dust (0-5 mm), 13% river sand (0-4 mm), 10% crushed stone (size 4-8 mm), 15% crushed stone (size 8-16 mm) and 30% crushed stone (size 16-24 mm) with bitumen content between 4.5% and 6.5% at varying increments of 0.5%. Blending was done at a temperature of 145-160ºC and allowed to reduce to a temperature of 145ºC before it was compacted on the two sides with 50 blows to obtain cylindrical samples [10]. Marshall Stability and flow tests were carried out at a temperature of 60ºC on the samples.

Table 1. Mix proportion in percent with specific gravities of the aggregates used

Aggregate sizes used	Mix proportion (%)	Specific gravity
16-24 mm crushed stone	30	2.760
8-16 mm crushed stone	15	2.677
4-8 mm crushed stone	10	2.670
0-5 mm stone dust	32	2.600
0-4 mm river sand	13	2.665
PKS	Varied	1.620

Table 2. Chemical content of palm kernel

Elemental oxidation:	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	K_2O
% composition:	54.81	11.4	0.36	8.79	6.11	6.25

Property:	Moisture content	Ash content	Lignin	Cellulose
% composition:	5.55	2.35	44.47	26.65

(Source: NAPRI & SRL)

Table 3. Properties of the bitumen used

Property	Test value
Specific gravity at 25ºC	1.03
Softening Point (Ball & Ring) ºC	52
Penetration at 25C - 0.1mm	60 - 70
Ductility at 25ºC (cm/min)	100
Loss on heating after 5 hours at 163ºC in % by weight of mix	0.2
Solubility in Trichloroethane % by weight	99
Drop in penetration after heating (%)	20
Flash point (open cup) ºC min	250
Ash % by weight	0.5

(Source: Julius Berger Asphalt Laboratory)

Table 4. Percentage passing at 30% PKS replacement

BS Sieve (mm)	% passing
31.75	-
25	100.0
19	87.4
12.5	63.9
9.5	57.1
4.75	46.0
2.36	37.1
1.18	29.3
0.6	22.0
0.3	13.2
0.15	6.7
0.075	3.3

(Note: Tables showing other Percentage passing at 0%, 50%, 70% and 100% PKS Replacement were derived)

Palm kernel shells were added at 0%, 30%, 50%, 70% and 100% by weight of total coarse aggregate size of 4-8 mm. Fifteen samples for control mix and sixty samples for the PKS proportions of compacted asphaltic mixtures were prepared in the laboratory and the average of the results for each mix proportion was determined and evaluated.

Table 1 shows the mix proportions of aggregates used for design mix and the results of their specific gravities. Table 2 shows the chemical composition of PKS showing its elemental oxidations and properties with their percentage compositions.

The mix design was decided on the basis of sieve analysis and the required amount of aggregates was oven dried for 4 hours at about 102ºC to 110ºC temperature so that free moisture of aggregate was removed. The oven-dried aggregates were allowed to cool and then weighed as per blending percentage and transferred to mixing pan back to oven before mixing with binder.

Fig. 1 shows grading envelope for the combined gradation at 30% PKS Replacement. Table 4 shows the percentage passing used for the combined gradation at 30% PKS Replacement for binder course [11].

3. RESULTS AND DISCUSSION

The suitability of mix for paving is decided on the basis of Marshall Stability and flow value, but some other parameters like unit weight of mix, percent air voids and voids in mineral aggregates are important to be taken into consideration for the durability of the flexible pavement.

Table 20 shows the comparison of Optimum Bitumen Content, physical and volumetric properties at mix proportions of PKS replacement.

From Table 20, almost all the OBC fall very close to the OBC at control mix and within the limits of specification. All the percent of PKS mix proportions except at 70% are within the limits of specification including the control mix. At 70% PKS replacement, the percent air void is very low about 1.4% utilizing this value will most likely cause rutting and bleeding of the flexible pavement because there will not be enough air voids for the bitumen to occupy during traffic loading.

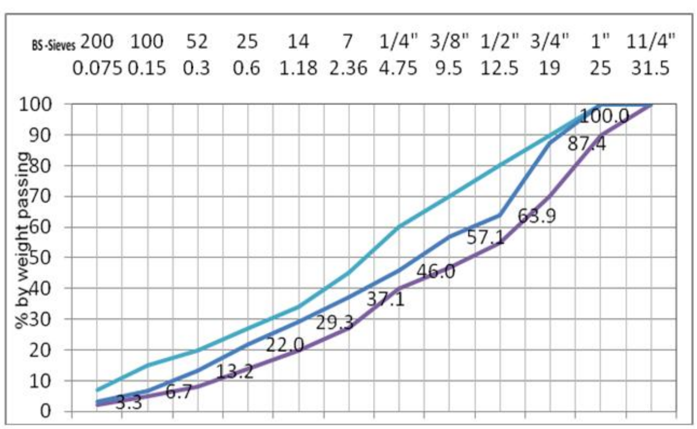

Fig. 1. Grading envelope at 30% PKS replacement

(Note: Figures showing other Grading Envelope at 0%, 50%, 70% and 100% PKS Replacement were derived.)

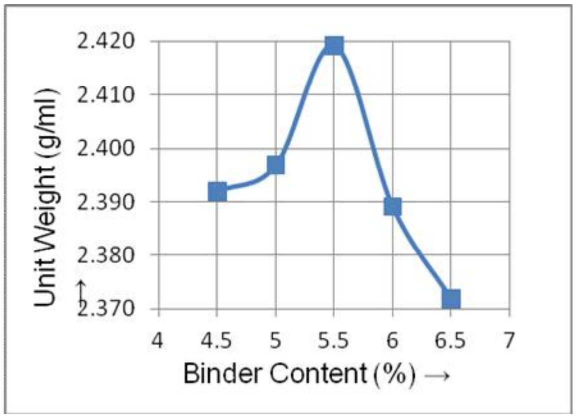

Fig. 2. Relationship between unit weight and binder binder content (at 0% PKS Replacement)

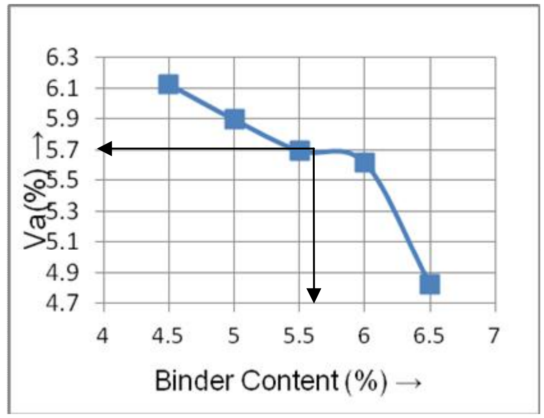

Fig. 3. Relationship between air void and content (at 0% PKS replacement)

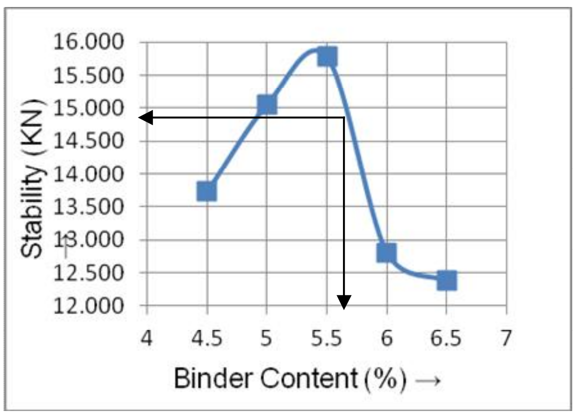

Fig. 4. Relationship between stability and binder with content (at 0% PKS replacement)

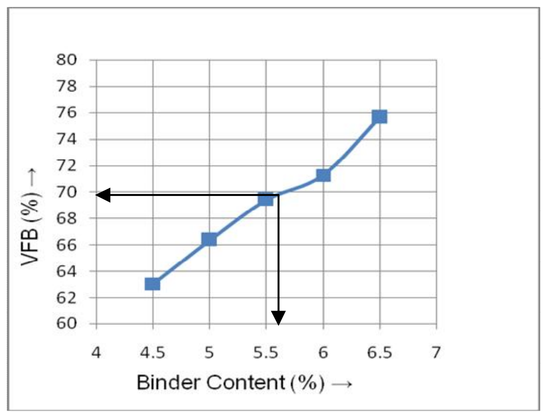

Fig. 5. Relationship between void filled bitumen and binder content (at 0% PKS replacement)

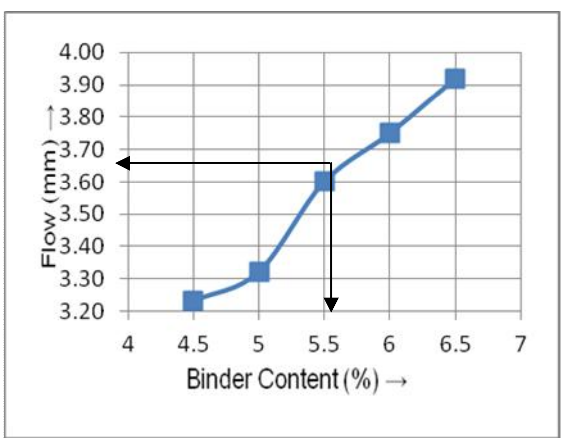

Fig. 6. Relationship between flow and binder content mineral (at 0% PKS replacement)

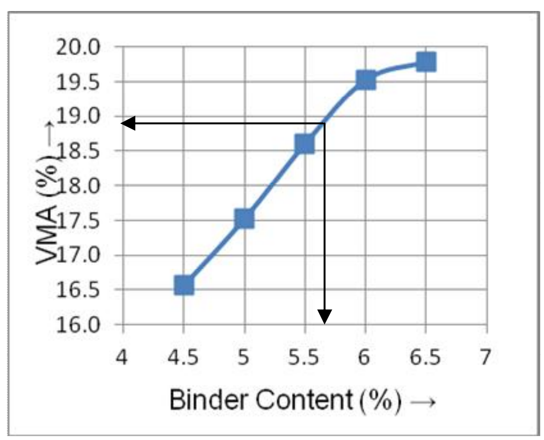

Fig. 7. Relationship between voids in aggregate and binder content (at 0% PKS replacement)

Note: Figures showing other Relationship between Volumetric and Physical properties with Binder Content *at 30%, 50%, 70% and 100% PKS Replacement were derived*

Table 5. Physical & volumetric properties of asphaltic concrete with 0% PKS replacement

Property						
Binder content (%)	**Unit weight (g/ml)**	**Va (%)**	**VFB (%)**	**VMA (%)**	**Stability (KN)**	**Flow (mm)**
4.5	2.392	6.1	63.0	16.6	13.730	3.23
5.0	2.397	5.9	66.4	17.5	15.054	3.32
5.5	2.419	5.7	69.4	18.6	15.779	3.60
6.0	2.389	5.6	71.3	19.5	12.812	3.75
6.5	2.372	4.8	75.6	19.8	12.384	3.92

Va: percent air voids, VFB: voids filled with Bitumen, VMA: voids in mineral Aggregate

Table 6. Optimum binder content value at 0% PKS replacement

	Properties		
	Max. unit weight	**Max. stability**	**Median of percent air voids**
Binder content (%)	5.5	5.4	6.2

Average Value = 5.7%

Therefore, Optimum Binder Content(OBC) at 0% PKS replacement = 5.7%

Table 7. Properties at 5.7% Optimum Binder Content at 0% PKS Replacement

Property	Value	Specification	Remarks
Stability(KN)	14.59	Not less than 3.5	Satisfactory
Flow(mm)	3.64	2 – 6	Satisfactory
Va(%)	5.70	3 – 5	Not satisfactory
VFB(%)	69.9	65 – 78	Satisfactory
OBC(%)	5.7	4.5 - 6.5	Satisfactory

Source of specification: Asphalt Institute

Table 8. Physical & volumetric properties of asphaltic concrete with 30% PKS replacement

Property						
Binder content (%)	**Unit weight (g/ml)**	**Va (%)**	**VFB (%)**	**VMA (%)**	**Stability (KN)**	**Flow (mm)**
4.5	2.300	3.7	73.1	13.8	10.649	3.70
5.0	2.345	4.4	72.3	15.7	10.938	3.50
5.5	2.367	4.1	75.5	16.7	10.382	3.23
6.0	2.338	4.8	73.8	18.4	13.227	3.19
6.5	2.346	5.2	73.9	20.0	12.160	3.52

Va: percent air voids, VFB: voids filled with Bitumen, VMA: voids in mineral Aggregate

Table 9. Optimum binder content value at 30% PKS replacement

	Properties		
	Max. unit weight	**Max. stability**	**Median of percent air voids**
Binder content (%)	5.5	6.1	-

Average Value = 5.8%

Therefore, Optimum Binder Content(OBC) at 30% PKS replacement = 5.8%

Values in Table 7 indicate that the control mix meets the criteria at 5.7% OBC excluding percent air void.

It implies that the mix at 30% meets the criteria at 5.8% OBC hence, it is satisfactory.

It implies that the mix at 70% does not meet all the specification at 6.1% OBC. It only meets the physical properties not the volumetric properties hence, it is not satisfactory. Bleeding and rutting are likely to occur.

It shows that the mix at 50% meets the criteria at 5.7% OBC hence, it is satisfactory.

Table 10. Parameters at 5.8% OBC for 30% PKS replacement

Property	Value obtained	Specification	Remarks
Stability (KN)	12.2	Not less than 3.5	Satisfactory
Flow (mm)	3.18	2 – 6	Satisfactory
Va (%)	4.5	3 – 5	Satisfactory
VFB (%)	74.9	65 – 78	Satisfactory
OBC (%)	5.8	4.5 - 6.5	Satisfactory

Table 11. Physical & volumetric properties of asphaltic concrete with 50% PKS replacement

Property						
Binder content (%)	**Unit weight (g/ml)**	**Va (%)**	**VFB (%)**	**VMA (%)**	**Stability (KN)**	**Flow (mm)**
4.5	2.267	5.8	63.2	15.7	10.923	3.55
5.0	2.296	5.9	65.3	17.1	11.000	3.43
5.5	2.317	3.8	76.6	16.2	9.119	3.52
6.0	2.287	3.7	78.3	17.0	10.840	3.82
6.5	2.299	5.9	70.9	20.5	11.519	3.60

Va: percent air voids, VFB: voids filled with Bitumen, VMA: voids in mineral Aggregate

Table 12. Optimum binder content value at 50% PKS replacement

	Properties		
	Max. unit weight	**Max. stability**	**Median of percent air voids**
Binder content (%)	5.5	6.5	5.2

Average Value = 5.7%
Therefore, Optimum Binder Content(OBC) at 50% PKS replacement = 5.7%

Table 13. Parameters at 5.7% OBC for 50% PKS replacement

Property	Value obtained	Specification	Remarks
Stability(KN)	9.4	Not less than 3.5	Satisfactory
Flow(mm)	3.6	2 – 6	Satisfactory
Va(%)	3.5	3 – 5	Satisfactory
VFB(%)	78.0	65 – 78	Satisfactory
OBC(%)	5.7	4.5 - 6.5	Satisfactory

Table 14. Physical & volumetric properties of asphaltic concrete with 70% PKS replacement

Property						
Binder content (%)	**Unit weight (g/ml)**	**Va (%)**	**VFB (%)**	**VMA (%)**	**Stability (KN)**	**Flow (mm)**
4.5	2.221	5.1	65.4	14.8	10.830	3.51
5.0	2.246	4.9	69.2	15.8	8.552	3.30
5.5	2.299	4.1	74.9	16.4	10.328	4.18
6.0	2.282	1.3	91.4	14.5	10.413	3.42
6.5	2.279	5.1	73.9	19.5	15.422	2.88

Va: percent air voids, VFB: voids filled with Bitumen, VMA: voids in mineral Aggregate

Table 15. Optimum binder content value at 70% PKS replacement

	Properties		
	Max. unit weight	**Max. stability**	**Median of percent air voids**
Binder content (%)	5.6	6.5	-

Average Value = 6.1%
Therefore, Optimum Binder Content(OBC) at 70% PKS replacement = 6.1%

Table 16. Parameters at 6.1% OBC for 70% PKS Replacement

Property	Value Obtained	Specification	Remarks
Stability(KN)	10.5	Not less than 3.5	Satisfactory
Flow(mm)	3.39	2 – 6	Satisfactory
Va(%)	1.40	3 – 5	Not satisfactory
VFB(%)	91.0	65 – 78	Not satisfactory
OBC(%)	6.10	4.5 - 6.5	Satisfactory

Table 17. Physical & volumetric properties of asphaltic concrete with 100% PKS replacement

Property						
Binder content (%)	**Unit weight (g/ml)**	**Va (%)**	**VFB (%)**	**VMA (%)**	**Stability (KN)**	**Flow (mm)**
4.5	2.145	8.0	54.1	17.3	10.033	3.48
5.0	2.214	4.6	69.9	15.4	8.521	3.53
5.5	2.203	4.4	72.8	16.2	5.005	4.23
6.0	2.198	4.2	75.5	17.0	8.947	3.18
6.5	2.205	6.9	66.9	20.8	10.654	3.73

Va: percent air voids, VFB: voids filled with Bitumen, VMA: voids in mineral Aggregate

Table 18. Optimum binder content value at 100% PKS replacement

	Properties		
	Max. unit weight	**Max. stability**	**Median of percent air voids**
Binder content (%)	5.5	5.4	6.2

Average Value = 5.5%
Therefore, Optimum Binder Content (OBC) at 100% PKS replacement = 5.5%

Table 19. Parameters at 5.5% OBC for 100% PKS replacement

Property	Value obtained	Specification	Remarks
Stability(KN)	5.10	Not less than 3.5	Satisfactory
Flow(mm)	4.25	2 – 6	Satisfactory
Va(%)	4.4	3 – 5	Satisfactory
VFB(%)	73.0	65 – 78	Satisfactory
OBC(%)	5.5	4.5 - 6.5	Satisfactory

It implies that the mix at 100% PKS replacement meets the criteria at 5.5% OBC hence, it is satisfactory.

It will reduce the durability. The voids filled with bitumen is too high about 91.0% which will definitely cause bleeding since there is low air void.

3.1 Parameters Trend from 0% - 100% PKS Replacement

Table 21 shows the stability parameter trend from 0% to 100% PKS replacement at different binder content ranging from 4.5% to 6.5% with the recommended value. Fig. 8 shows the graph of stability plotted against percent PKS replacement.

It is observed that there is decrease in stability from 0% to 100% mix proportions of PKS replacement. Stability has peak value of 15.779KN at 5.5BC% of 0% PKS replacement. Stability has lowest value of 5.0KN at 5.5BC% of 100% PKS replacement. The trend shows about 65% reduction in stability but the lowest value obtained is still within the specified limit. However, other properties have to be considered here before conclusion. For instance, mixes with very high stability value and low flow value are not desirable as the pavements constructed with such mixes are likely to develop cracks due to heavy moving loads. In asphalt mix design, high durability is usually obtained at the expense of low stability. Hence, a balance has to be struck between the durability and stability requirements.

Table 22 shows the flow parameter trend from 0% to 100% PKS replacement at different binder content ranging from 4.5% to 6.5% with the recommended value. Fig. 9 shows the graph of flow plotted against percent PKS replacement.

Table 20. Comparison of properties at mix proportions of PKS replacement

Property	0%	30%	50%	70%	100%	Specification
Stability(KN)	14.59	12.20	9.4	10.5	5.10	Not less than 3.5
Flow(mm)	3.64	3.18	3.6	3.39	4.25	2 – 6
Va(%)	5.7	4.5	3.5	1.40	4.40	3 – 5
VFB(%)	69.9	74.9	78.0	91.0	73.00	65 – 78
OBC(%)	5.7	5.8	5.7	6.10	5.5	4.5 - 6.5

Va: percent air voids, VFB: voids filled with Bitumen, OBC: Optimum Binder Content

Table 21. Stability parameter trend from 0% - 100% PKS replacement

	Stability (KN)					Specification
Binder content (%)	0%	30%	50%	70%	100%	
4.5	13.730	10.649	10.923	10.830	10.033	
5.0	15.054	10.938	11.000	8.552	8.521	
5.5	15.779	10.382	9.119	10.328	5.005	Not Less than 3.5KN
6.0	12.812	13.227	10.840	10.413	8.947	
6.5	12.384	12.160	11.519	15.422	10.654	

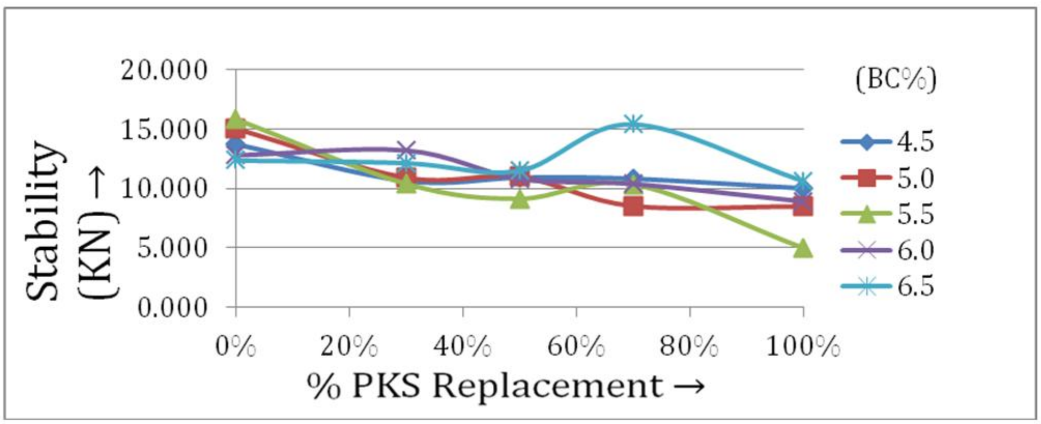

Fig. 8. Graph of Stability trend from 0% to 100% PKS Replacement

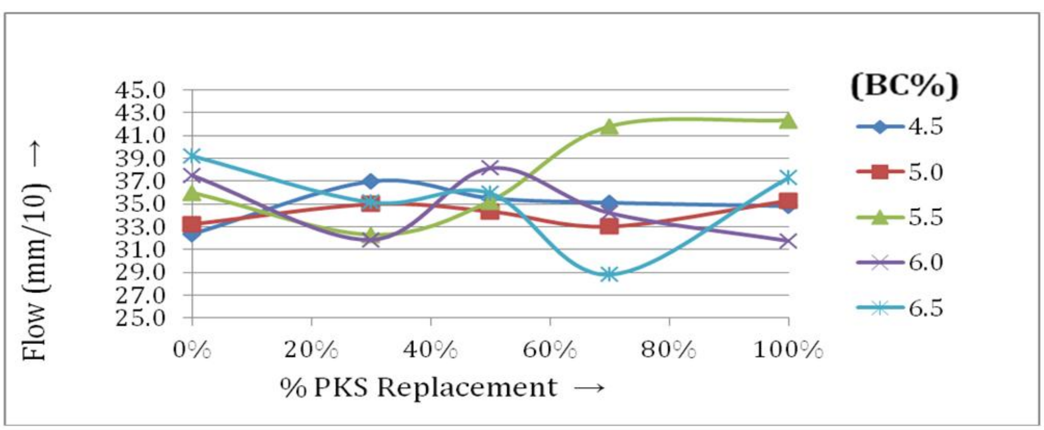

Fig. 9. Graph of flow trend from 0% to 100% PKS replacement

The asphalt mix at 5.5% BC has the highest value of 4.23 mm flow at 100% replacement of PKS while at 6.5% BC has the lowest value of 2.88mm flow at 70% replacement. It implies that palm kernel shell up to 100% replacement can be used in the production of hot mix asphalt. However, effective percentage utilization of PKS will be at the Optimum Binder Content.

Table 23 shows the unit weight parameter trend from 0% to 100% PKS replacement at different binder content ranging from 4.5% to 6.5%. Fig. 10 shows the graph of unit weight plotted against percent PKS replacement as shown in.

There is a sharp decrease in the unit weight as the percent of PKS is increased from 0% to 100%. The higher the PKS replacement, the lower the unit weight. Maximum unit weight is achieved at 5.5% of the design mix while the minimum unit weight is achieved at 4.5% at 100% PKS replacement. There is no recommended range for unit weight. The trend shows about 11% reduction in unit weight. It is observed that, unit weight and air void content are somehow related. The mix requires pavement density that produces the proper amount of air void in the pavement.

Table 24 shows the percent air void parameter trend from 0% to 100% PKS replacement at different binder content ranging from 4.5% to 6.5%. Fig. 11 shows the graph of percent air void plotted against percent PKS replacement.

It is observed that the percent air voids has its lowest value of 1.3% at 70% PKS replacemet with 6.0% BC and highest value of 8% is observed at 100% PKS replacement with 4.5% BC. As bitumen content is varied with percent PKS replacement some are outside the recommended range of values while some are within the specification range. However, the value of percent air void obtained at 5.7% Optimum Bitmen Content is 3.5% and this is within the recommended range (Table 20). The durability of an asphalt pavement is a function of the air void content.

Table 22. Flow parameter trend from 0% - 100% PKS replacement

	Flow (mm)					Specification
Binder content (%)	**0%**	**30%**	**50%**	**70%**	**100%**	
4.5	3.23	3.70	3.55	3.51	3.48	
5.0	3.32	3.50	3.43	3.30	3.53	
5.5	3.60	3.23	3.52	4.18	4.23	(2 mm – 6 mm)
6.0	3.75	3.19	3.82	3.42	3.18	
6.5	3.92	3.52	3.60	2.88	3.73	

Table 23. Unit weight parameter trend from 0% - 100% PKS replacement

	Uw (g/ml)					Specification
Binder content (%)	**0%**	**30%**	**50%**	**70%**	**100%**	
4.5	2.392	2.300	2.267	2.221	2.145	
5.0	2.397	2.345	2.296	2.246	2.214	
5.5	2.419	2.367	2.317	2.299	2.203	N/A
6.0	2.389	2.338	2.287	2.282	2.198	
6.5	2.372	2.346	2.299	2.279	2.205	

Uw: Unit Weight

Table 24. Percent air voids parameter trend from 0% - 100% PKS replacement

	Va (%)					Specification
Binder content (%)	**0%**	**30%**	**50%**	**70%**	**100%**	
4.5	6.1	3.7	5.8	5.1	8.0	
5.0	5.9	4.4	5.9	4.9	4.6	
5.5	5.7	4.1	3.8	4.1	4.4	(3 mm-5 mm)
6.0	5.6	4.8	3.7	1.3	4.2	
6.5	4.8	5.2	5.9	5.1	6.9	

Va: Percent Air Voids

Table 25 shows the voids filled with bitumen parameter trend from 0% to 100% PKS replacement at different binder content ranging from 4.5% to 6.5%. Fig. 12 shows the graph of voids filled with bitumen plotted against percent PKS replacement.

It can be seen that, at 70% PKS replacement there is a peak value of 91.4% at 6.0% BC while the lowest value is 54.1% at 4.5% BC. The peak value obtained is too high outside the range of recommended value likewise the lowest value. However, result has been obtained on the basis of the optimum binder content (Table 20).

If the VFB is too low, there is not enough asphalt to provide durability and to over-densify under traffic and bleed. A low VFB may result in a high air voids, and a high VFB may result in a low air voids.

Table 26 shows the Voids in Mineral Aggregate parameter trend from 0% to 100% PKS replacement at different binder content ranging from 4.5% to 6.5%. Fig. 13 shows a graph of Voids in Mineral Aggregate plotted against percent PKS replacement.

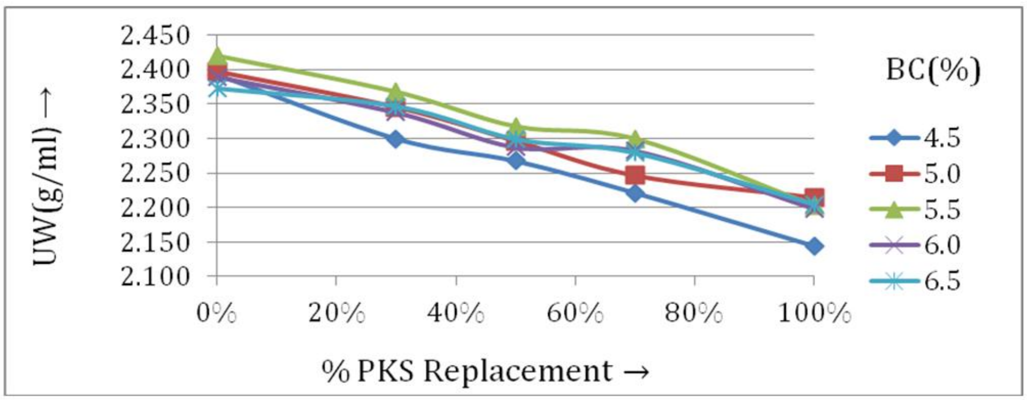

Fig. 10. Graph of unit weight trend from 0% to 100% PKS replacement

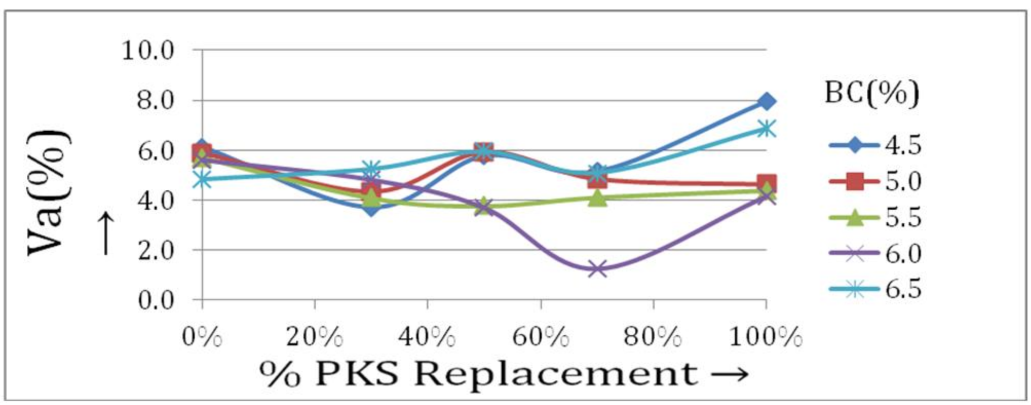

Fig. 11. Graph of percent air voids trend from 0% to 100% PKS replacement

Table 25. Voids filled with bitumen parameter trend from 0% - 100% PKS replacement

	VFB (%)					Specification
Binder content (%)	**0%**	**30%**	**50%**	**70%**	**100%**	
4.5	63.0	73.1	63.2	65.4	54.1	
5.0	66.4	72.3	65.3	69.2	69.9	
5.5	69.4	75.5	76.6	74.9	72.8	(65%-78%)
6.0	71.3	73.8	78.3	91.4	75.5	
6.5	75.6	73.9	70.9	73.9	66.9	

VFB: Voids Filled with Bitumen

At 6.5% BC, it is observed that the VMA value increases from 19.8% to 20.8%. The lowest value is 13.8% at 4.5% BC of 30% PKS replacement. The criteria for voids in mineral aggregate is related to the norminal maximum aggregate size with percent air voids which must be 13% minimum. It is observed that both the highest and lowest values meet the requirement.

VMA represents the space that is available to accommodate the asphalt and the volume of air voids necessary in the mixture.

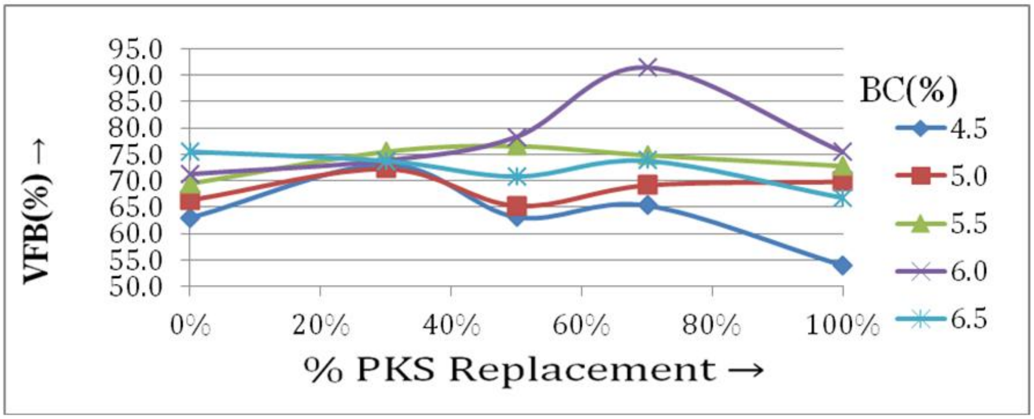

Fig. 12. Graph of voids filled with bitumen trend from 0% to 100% PKS replacement

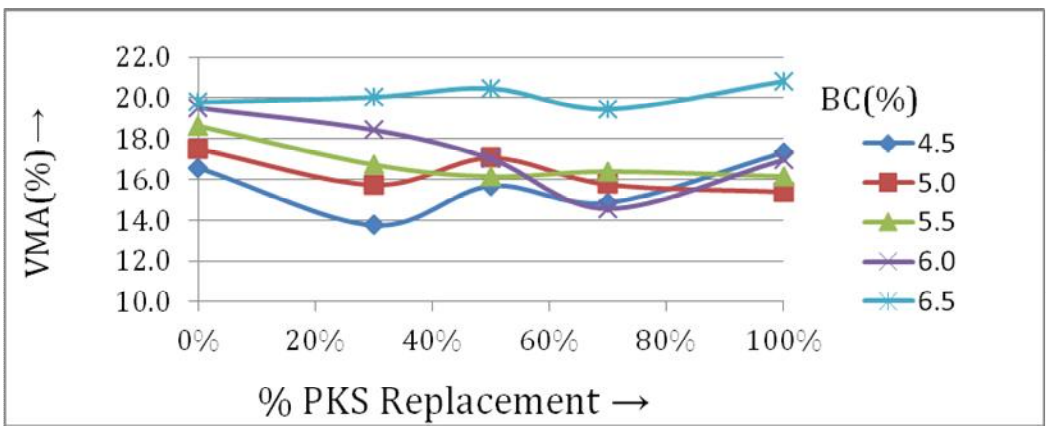

Fig. 13. Graph of Voids in mineral aggregate trend from 0% to 100% PKS Replacement

Table 26. Voids in mineral aggregate parameter trend from 0% - 100% PKS replacement

	VMA (%)					Specification
Binder content (%)	**0%**	**30%**	**50%**	**70%**	**100%**	
4.5	16.6	13.8	15.7	14.8	17.3	
5.0	17.5	15.7	17.1	15.8	15.4	
5.5	18.6	16.7	16.2	16.4	16.2	Not less than 13%
6.0	19.5	18.4	17.0	14.5	17.0	
6.5	19.8	20.0	20.5	19.5	20.8	

VMA: Voids in Mineral Aggregate

4. CONCLUSION

From the results obtained in this experiment, it can be concluded that effective optimum quantity of palm kernel shells replacement with crushed stone of 4-8 mm is at 50% replacement in binder course at 5.7% OBC. PKS here can be used under medium traffic and definitely with a road carrying a light traffic.

In view of the above, it is recommended that PKS can be used in the production of asphaltic concrete for the construction of medium trafficked roads.

ACKNOWLEDGEMENTS

The authors acknowledge the efforts of Julius Berger Asphalt laboratory staff for their technical assistance.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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The peer review history for this paper can be accessed here:
http://sciencedomain.org/review-history/9891