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DEVELOPMENT AND ENGINEERING CHARACTERIZATION OF AGRO WASTE MODIFIED ASPHALTIC CONCRETE FOR SUSTAINABLE GREEN HIGHWAYS

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ABSTRACT

Lately, the asphalt construction industry has been cumbered, not only by the high cost of bitumen, but with dearth and expensive cost of conventional mineral aggregates used in the production of asphaltic concrete. Consequently, this has resulted into the increasing cost of highway construction currently experienced in most developing countries and leaving so many roads unpaved and in worse conditions. Similarly, the agricultural industry has been challenged with the problem of disposal of agricultural wastes such as palm kernel shells. They are usually found littering farms and are often injurious to farm workers. A synergistic way of addressing the aforementioned challenges facing both industries is to recycle the agricultural wastes in the road construction industry. This research therefore evaluated the effect of partial replacement of coarse and fine aggregates with Graded Palm Kernel Shell (GPKS) and Crushed Palm Kernel Shell (CPKS) respectively in asphaltic concrete using Artificial Neural Network (ANN). In order to determine the performance indices of GPKS and CPKS in the mass production of binder course asphaltic concrete for low, medium and heavily trafficked roads, the physical, mechanical and volumetric properties of modified asphalt mixtures were evaluated. Coarse and fine aggregates were partially replaced with GPKS and CPKS respectively in proportions of 0%, 10%, 20%, 30%, 40% and 50% by weight of bitumen content. Precisely, 5 samples containing GPKS and CPKS proportions of compacted asphalt mixtures and1 sample for control mix were prepared using Marshall mixing procedure. This involved varying bitumen contents from 5% to 7% at an interval of 0.5%.Testing was done using the Marshall method in accordance with American Standard for Materials and Testing (ASTM D 1559: 2004). Results revealed *that 30% replacement of coarse and fine aggregates with the GPKS and CPKS in the same mix was within the Asphalt Institute Standard Specifications for bituminous surfacing with an Optimum Bitumen Content (OBC) of 5.8%, Marshall Stability of 10.98KN, and Flow of 8.0mm. The ANN training was done in three layers the by feed-forward multilayer perceptron. The three layers are the input layer, output layer and hidden layer. Each layer consists of neurons. The number of input variables(% PKS & CPKS, Wt. in air and Wt. in water) and the output variables (Density, Volume of bitumen (V_b), Stability, Flow, Volume of voids (Vv), Voids in Mixed Aggregates (VMA) and Voids Filled with Bitumen (VFB) respectively, determined the number of neurons in the input and output layers. The performance of the test data set for the developed ANN model was measured statistically by the Root Mean Square Error (RMSE), Mean Prediction Error (MPE) and the Absolute Fraction of Variance (AFV). The RMSE, MPE and AFV values obtained are 0.0766, 0.0606 and 0.9986 respectively for density, 0.0082, 0.0009 and 0.9985 respectively for V_b, 0.6001, 0.4107 and 0.9987 respectively for stability, 2.6408, 1.4937 and 0.9462 respectively for flow, 1.6815, 0.1626 and 0.999 respectively for Vv, 4.3853, 2.2343 and 0.9523 respectively for VMA and 1.1388, 0.7177 and 0.9999 respectively for VFB. From these values it could be inferred that the ANN model was able to effectively learn and predict all outputs investigated. In conclusion, for medium trafficked roads, GPKS and CPKS between 10%-30% vis-à-vis the weight of coarse and fine aggregates can be used as substitute while up to 50% replacement is conceivable for rural and farm roads that are lightly pliedto reduce cost of construction and encourage construction of sustainable pavements.*

Keywords: Artificial Neural Network (ANN), Mineral Aggregates, Graded Palm Kernel Shell (GPKS), Crushed Palm Kernel Shell (CPKS), Marshall Stability, Flow, Optimum Bitumen Content (OBC), ANN Model, Sustainable Pavements.

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1. INTRODUCTION

Over time, in the highway pavement construction industry, there has been over dependence on conventional aggregates such as crushed and well graded granite, sand, filler materials and binder, usually bitumen for production of asphaltic concrete and construction of roads [1].Besides, the increasing price of these naturally occurring materials hasimmenselystalled the development of flexible pavement infrastructure, including sustainable roads in the rural areas of developing countries [2].In order to promote sustainable transportation, coupled with efforts by the industry to mitigate the aforementioned challenges, transportation policy makers and the road paving industry are increasingly considering the use of readily available and locally sourced alternative materials such as oil palm wastes in form of Palm Kernel Shells (PKS) and Crushed Palm Kernel Shells (CPKS). Palm kernel originated from oil palm tree (*elaeisguineensis*), which is commonly found in Western Africa and widespread throughout the tropics and is comprised of two species of the *arecaceae*or palm family [3].


Fig. 1. (a)Fresh Palm Kernel (b)Palm Kernel Bunches

Source : [5]

Due to its economic value, oil palm shells are used in commercial agriculture in the production of palm oil. The African oil palm (*elaeisguineensis)* is native to West Africa, occurring between Angola and Gambia, while the American oil palm *elaeis oleifera is* native to tropical Central America and South America [4]. The generic name is derived from the Greek word for oil, *elaion,* while the species name refers to its country of origin. [5] reported that oil palm trees can be found in large quantities in America, Asia and Africa, especially in Nigeria. In Nigeria, about 1.5 million tons of palm kernel shells are produced per annum; most of which are often dumped as waste products [6]. These wastes can therefore be transformed to wealth, by utilizing them to produce asphaltic concrete, a major surfacing material in pavement construction. Oil palm shells are not common materials in the pavement construction industry [7]. This is either because they are not available in very large quantities as sand or gravel, or because their use for such, has not been encouraged. However, investigation into the use of alternative materials has been engendered by the increasing cost of the aforementioned conventional pavement materials, high pavement construction costs, environmental ruin by agricultural wastes and depletion of conventional materials [7], [16]. The use of such replacement materials contributes not only to construction cost reduction but reduces impact on the environment. Researchers, although limited have studied the effects and performance of PKS in bituminous mixtures as partial replacement of both coarse and fine aggregates majorly on dense graded asphalt but analyses focused more on the physical and mechanical properties (stability and flow) with little or no assessment of the volumetric properties. Based on stability and flow[8], investigated the performance of palm kernel shells as partial replacement for coarse aggregate in asphalt concrete. He observed that Palm kernel shells can be used as partial replacement for coarse aggregate up to 10% for heavily trafficked roads and 50% for light trafficked roads. Similarly, [1], [18] investigated palm kernel shell substitution for aggregates in asphaltic concrete with positive marshal stability values. [5], [17]studied the properties of coconut shells and palm kernel shells as coarse aggregates in concrete. The coconut shells were processed by crushing them and substituted for conventional coarse aggregates in gradations of 0%, 25%, 50%, 75% and 100%. Two mix ratios (1:1:2) and (1:2:4) were used respectively. They observed that there was a decrease in the compressive strength of the concrete as the proportion of the shells increased for the two mix ratios. However, concrete obtained from coconut shells exhibited a higher compressive strength than palm kernel shell concrete in the two proportions. Research has also been carried out on effect of partial replacement on workability and strength. [9] studied the effect on workability and strength of the resultant mix of partially replacing aggregates with palm kernel shells, incorporating palm kernel fibre. Flexural and compressive strength effects where investigated by [10], by utilising coconut shells as partial replacement for aggregates. Studies aforementioned have thus majorly focused on stability and flow. This study however puts into consideration and inclusion, the influence of volumetric attributes using GPKS and

CPKS on the Marshall properties of a new bituminous mix using ANN prediction modelfor applicable recommendation for sustainable pavement works.

2. EXPERIMENTAL SECTION

2.1 Materials

The materials used in this research for this purpose are bitumen, of Penetration Grade (PG) 60/70, mineral aggregates, GPKS and CPKS.

Fig. 2:Graded Palm Kernel Shells

Fig. 3: Crushed Palm Kernel Shells

2.1.1. Material Identification and Preparation

The bitumen of PG 60/70 was sourced from the highway and transportation laboratory of Landmark University, OmuAran, Nigeria. The viscous material was subjected to various laboratory tests such as specific gravity test, penetration test using automatic penetrometer to ascertain its actual grade. The conventional coarse aggregates used for the purpose of this research were screened crushed rocks, angular in shape, washed free from dust particles, clay, vegetation and organic matters and there were found to offer compressive and shear strength and show good interlocking properties through appropriate Aggregate Impact Value (AIV) and Aggregate Crushing Value tests and hence retained on sieve 4.75 mm [11]. Further tests revealed specific gravity of 2.60. The Fine aggregates used where well cleaned and screened quarry dusts, free from clay, loam, vegetation or organic matter. Fine aggregates passed sieve 4.75 and 1.18 and retained in sieve 0.600µm IS sieve. These mineral aggregates where obtained from KOPEK Quarry Yard, Ibadan Nigeria. The Palm kernel shell used in this research was gotten locally from the traders in the OmuAran market. Pre-treatment of the shells was carried out by removing the oil coating with detergent and water [19]. Thereafter, they were washed and dried and then sieved into the required particle sizes. A part was taken to the Landmark University commercial farm for crushing by the miller.

2.2. Experimental Procedure

The experimental procedure for this study began with the production of control samples by mixing specific proportions of each constituent material viz 6% Filler (0.075mm), 21% quarry (5mm), and 68% crushed stone (5-16mm),and 5% bitumen (PG 60/70) together at 163˚C. The mixture was compacted with 50 blows were applied both at the top and bottom of the samples for the Marshall Stability tests. Palm kernel shells were fractionally substituted at 10, 20, 20, 30, 40 and 50% by weight of total conventional coarse aggregate in the mixture. Figure 4 shows the six (6) samples prepared for each percentage replacement of coarse aggregates with PKS. Similar procedure was replicated for CPKS as substitute for fine aggregates.

Figure 4 Samples Prepared for Marshall Test

2.2.1. Laboratory Investigations

The laboratory tests conducted include, grain size analysis, ductility test, Penetration test, softening point test, aggregate impact test and marshal stability test. The study was conducted through standardized laboratory test methods following set standards and specifications such as:

Sieve Analysis

Particle size analysis of the PKS, CPKS and mineral aggregates was carried out in accordance with ASTM C136-06 (ASTM, 2014) by passing them through a set of sieves to determine specific aggregate sizes and their gradation. On completion of the sieving the weights of material retained on each sieve were noted down and the results were reported on the particle size distribution sheet as cumulative percentage by weight of sample passing each of the sieves.

Aggregate Impact Value (AIV) Test

Aggregates passing through 12.5 mm IS sieve and retained on 10 mm sieve were filled in the cylindrical measure in 3 layers by tamping each layer by 25 blows in order to obtain the net weight W1, and the fraction passing through IS 2.36 mm sieve (W2). AIV was determined according to [12] as the measure of the suitability of aggregate as regards the toughness for use in pavement construction as given by equation (1).

$$\frac{W_2}{W_1} X\, 100\% \qquad \text{Eqn(1)}$$

Where: W_1 = Weight of fines passing 2.36 mm
W_2 = Weight of sample

Aggregate Crushing Value (ACV) Test

Aggregates in a cylindrical measure are subjected to load at a rate of 4 tonnes per minute up to 40 tonnes according to [12], The ACV, being a measure of the resistance to crushing under a constantly applied compressive load is given by the equation 2.

$$\frac{W_1}{W_2} X\,100\% \qquad \text{Eqn(2)}$$

Where: W_1 = Weight of crushed material
W_2 = Weight of sample

Specific Gravity Test

Specific gravity test for coarse and fine aggregates respectively was carried out according to (ASTM C127 - 12 and ASTM C128 - 12) (ASTM, 2012b).

Bitumen Penetration Test

Penetration test was carried out according to (BS 2000-487:2009) (BS, 2000).

Marshall Stability Test

Marshal stability test was carried out in accordance with (ASTM D 6927 – 06) (ASTM, 2006).All tests were conducted at the Highway and Geotechnical Engineering Laboratory of Civil Engineering Department, Landmark University.

Marshal Mix Design Parameters

Special parameters for the marshal mix design such as specific gravity, bulk density, volume of air voids, volume of bitumen, voids filled with bitumen, voids in mineral aggregates were determined by the following formulae respectively:

Specific Gravity of Asphalt mix, $Gt = \frac{W1+W2+W3+Wb}{\frac{W1}{G1}+\frac{W2}{G2}+\frac{W3}{G3}+\frac{Wb}{Gb}}$ [13] Eqn (3)

Where;
W1 = the weight of coarse aggregates in the total mixture
W2= the weight of fine aggregates in the total mixture
W3 = the weight of filler in the total mixture
Wb = the weight of bitumen in the total mixture
G1 = the apparent specific gravity of coarse aggregates
G2= the apparent specific gravity of fine aggregates
G3 = the apparent specific gravity of filler
Gb = the apparent specific gravity of bitumen

Bulk density, $Gm = \frac{Wm}{Wm-Ww}$ [13] Eqn 4

Where;
Wm = weight of mix in air
Ww = weight of mix in water

Air voids, $Vv = \frac{Gt-Gm*100}{Gt}$ Eqn. 5

% Volume of bitumen, $Vb = \frac{\frac{Wb}{Gb}}{\frac{W1+W2+W3+Wb}{Gm}}$[15] Eqn.6

Voids in mineral, $VMA = Vv + Vb$Eqn 7

Voids filled with bitumen, $VFB = \frac{Vb*100}{VMA}$[15] Eqn.8

2.3. ANN Analysis

The ANN modelling was done using the CPC- X software, 2004 [14]. The splitting of the data into testing and training sets was done to ensure stability of the network. The test numbers for the test data set are 1, 5 and 9 while the training data set are test numbers 2,3,4,6,7,8 and 10 as presented in Table 1. The ANN training was done by feed-forward multilayer perceptron consisting of three layers. These layers are the input layer, hidden layer and output layer. Each layer consists of neurons. The number of neurons in the input and output layers are determined by the number of input variables (% PKS & CPKS,Wt. in air and Wt. in water) and the output variables (Density, Vol. of bitumen, Stability, Flow, Vv, VMA and VFB) respectively. A single hidden layer with the number of neurons varied from five and ten in order to achieve an optimum architecture. This optimum architecture was achieved with seven neurons in the hidden layer as presented in Figure 5. The transfer function for hidden and output layers was the hyperbolic tangent. The Quick propagation which is a form of back propagation algorithm was used for training. The number of iterations and time elapsed at the end of training was 15,100 at elapse time of 5s respectively. The statistical consistency of the ANN trained model was measured using the root mean square error (RMSE), mean prediction error (MPE) and the absolute fraction of variance (AFV). The number of iterations and time elapsed at the end of training was 17,223 at elapse time of 6s respectively. The generalization capacity of the test data set was determined by the RMSE, MPE, andAFV.

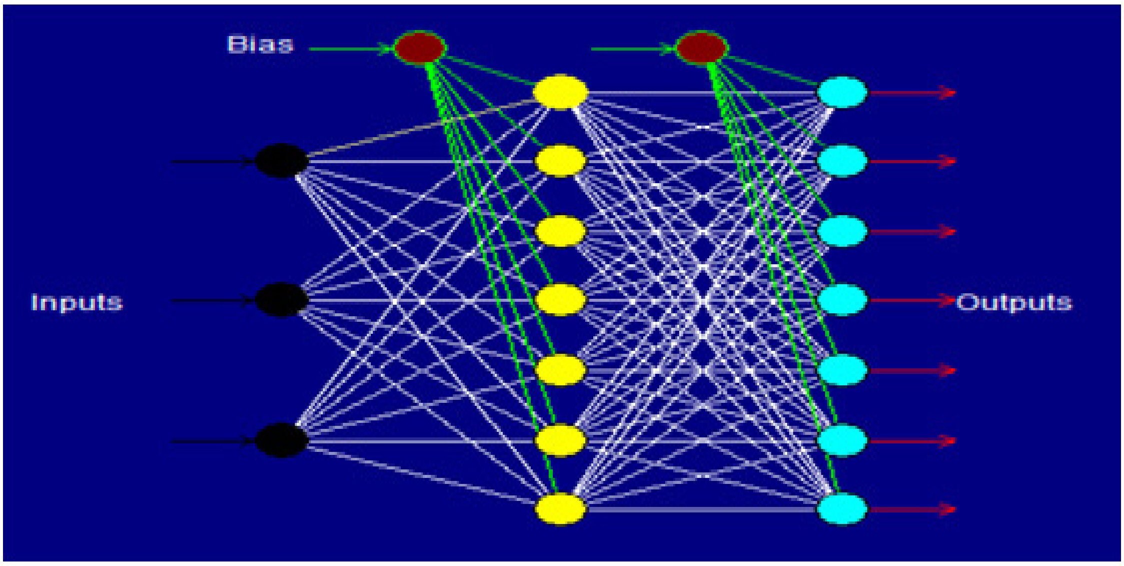


Figure 5 Optimum architecture of the ANN model

Table 1 ANN Test Numbers for Marshall and Volumetric Properties (Bold characters represent the test data set of the constructed ANN models)

Test No.	*% PKS & CPKS*	*Wt. in air (g)*	*Wt. in water (g)*	*Density g/cm^3*	*Vol. of bitumen (V_b)*	*Stability (Kg)*	*Flow (mm)*	*Vv (%)*	*VMA*	*VFB (%)*
1	0	1782.5	1107.9	2.64	0.13	2599.5	12	3.7	16.77	**84**
2	10	1700.6	1039.4	2.51	0.13	2305.5	9.5	3.98	20.67	79.25
3	20	1633.3	934.7	2.33	0.14	1157.58	12	4.2	10.46	77.13
4	30	1502.1	823.6	2.21	0.15	1098.72	8	4.63	10.54	79.01
5	40	1321.9	712.3	2.16	0.17	1216.44	12.1	5.22	16.31	**76.34**
6	50	1233	613	1.98	0.17	1000.62	12	5.62	17.22	78.9
7	60	1151.1	476.5	1.85	0.19	706.62	12.5	5.86	21.12	80.82
8	70	1083.8	422.6	1.67	0.2	647.76	13.3	6.14	15.35	82.57
9	80	952.6	274.1	1.55	0.22	431.94	13.52	6.33	19.25	**84.88**
10	90	772.4	162.8	1.42	0.24	373.36	14.83	6.63	23.15	85.13

3. RESULTS AND DISCUSSION

This section presents the results of laboratory tests on control sample as well as the partially replaced samples.

3.1. Particle Size Distribution

The combined particle size distribution curves on the logarithmic scale for coarse aggregates, fine aggregates, palm kernel shell and crushed palm kernel shell used in the preparation of asphaltic concrete are as shown in Table 2 and Figure 6. From the graph, the coefficient of uniformity is 4.75 and the coefficient of curvature is 1.07. This implies that the aggregates are well graded and can be utilized for production of light weight concrete and road pavement construction.

Table 2 Particle Size Distribution Data for CPKS, GPKS, FA and CA [ASTM D422-63(2007)]

Sieve Diameter (mm)	Soil Retained CA (g)	Soil Retained FA (g)	Soil Retained GPKS (g)	Soil Retained CPKS (g)	Soil Retained CA (%)	Soil Retained FA (%)	Soil Retained GPKS (%)	Soil Retained CPKS (%)	Soil Passing CA (%)	Soil Passing FA (%)	Soil Passing GPKS (%)	Soil Passing CPKS (%)
19	0	0	0	0.0	0.0	0.0	0.0	0.0	100.0	100.0	100.0	100.0
12.7	526	134.1	0	0	26.3	6.7	0.0	0.0	73.7	93.3	100.0	100.0
9.52	395	134	0	0	19.8	6.7	0.0	0.0	54.0	86.6	100.0	100.0
4.75	285	200	0	0	14.3	10.0	0.0	0.0	39.7	76.6	100.0	100.0
2.36	254	305	210	256	12.7	15.3	21.0	25.6	27.0	61.3	79.0	74.4
1.18	106	222.5	233.5	224.5	5.3	11.1	23.4	22.5	21.7	50.2	55.7	52.0
0.6	175	370.9	199.9	187.5	8.8	18.5	20.0	18.8	13.0	31.7	35.7	33.2
0.425	181	250	150	130.9	9.1	12.5	15.0	13.1	3.9	19.2	20.7	20.1
0.3	44.5	200	100	129.7	2.2	10.0	10.0	13.0	1.7	9.2	10.7	7.1
0.15	33.5	183.5	76.5	44.5	1.7	9.2	7.7	4.4	0.0	0.0	3.0	2.7
0.075	0	0	30.1	27.0	0.0	0.0	3.0	2.7	0.0	0.0	0.0	0.0
PAN	0	0	0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
TOTAL:	**2000**	**2000**	**1000.0**	**1000.0**	**100.0**	**100.0**	**100.0**	**100.0**				

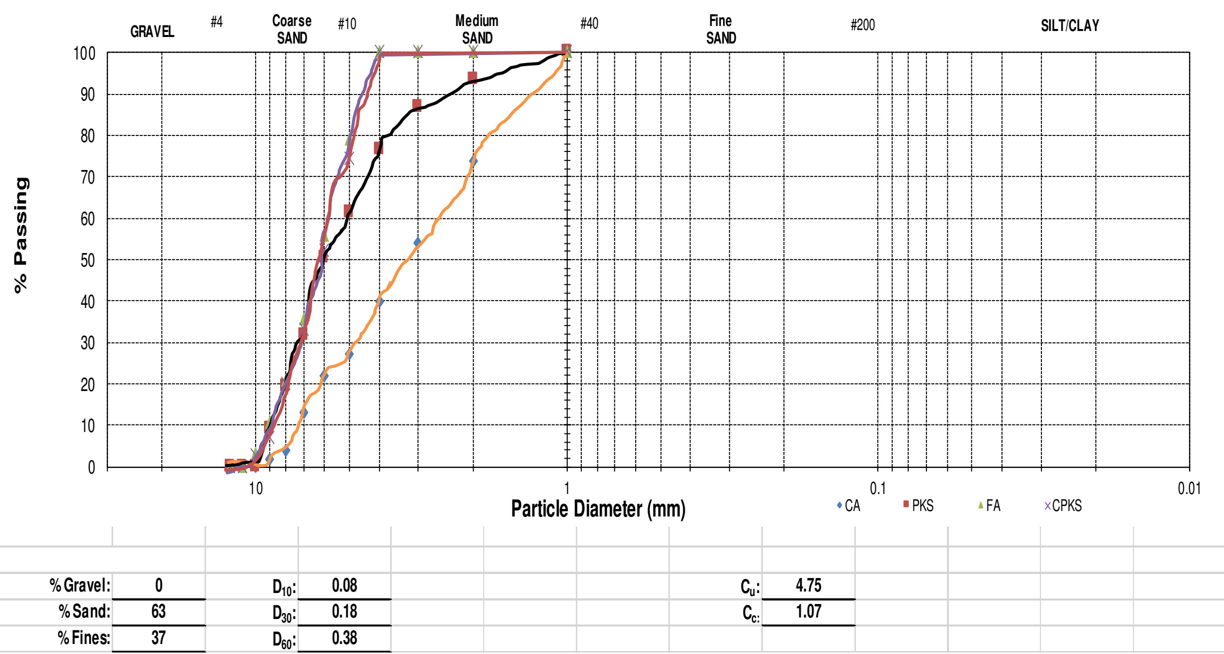


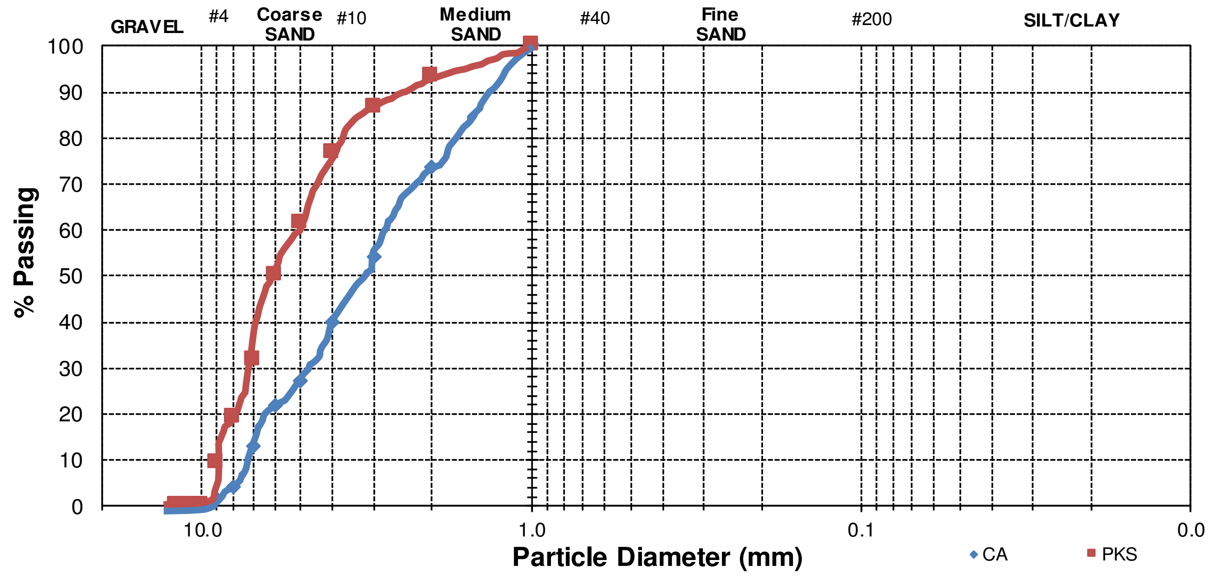
Figure 6 Combined Particle Size Distribution Curves CPKS, GPKS, FA and CA

A comparison was made between the particle size distribution curves for coarse aggregates and palm kernel shells and between fine aggregates and crushed palm kernel shell as shown in Table 3 and Figure 7, Table 4 and Figure 8 respectively. Comparison between GPKS and CA shows no significant difference in the particle grading properties between these materials. For the comparison between FA and CPKS, it was found that there were similarities between the materials properties which made them suitable replacements or alternatives for each other.

Table 3 Particle Distribution Data for GPKS and CA.

Weight of Container (g):	450.0	Weight of Container & Soil (g):		2000.0
Weight of Dry Sample (g):	1550.0	ASTM D422-63(2007)		

Diameter (mm)	Diameter (mm)	Soil Retained CA (g)	Soil Retained GPKS (g)	Soil Retained CA (%)	Soil Retained GPKS (%)	Soil Passing CA (%)	Soil Passing GPKS (%)
19	19	0	0	0	0.0	100.0	100.0
12.7	12.7	526	134.1	26.3	6.7	73.7	93.3
9.52	9.52	395	134	19.75	6.7	54.0	86.6
4.75	4.75	285	200	14.25	10.0	39.7	76.6
2.36	2.36	254	305	12.7	15.3	27.0	61.3
1.18	1.18	106	222.5	5.3	11.1	21.7	50.2
0.6	0.6	175	370.9	8.75	18.5	13.0	31.7
0.425	0.425	181	250	9.05	12.5	3.9	19.2
0.3	0.3	44.5	200	2.225	10.0	1.7	9.2
0.15	0.15	33.5	183.5	1.675	9.2	0.0	0.0
0.075	0.075	0	0	0	0.0	0.0	0.0
PAN	PAN	0	0	0	0.0	0.0	0.0
TOTAL:		2000	2000	100.00	100.0		



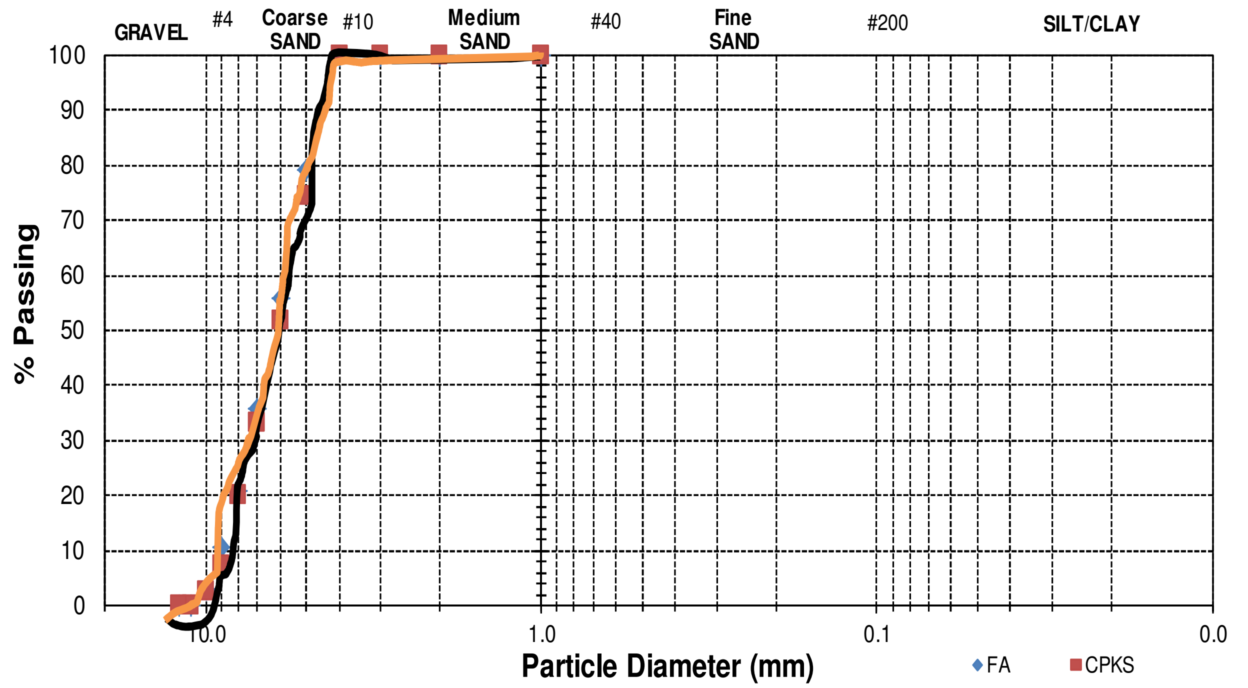
Grain Size Distribution Curve Results:					
% Gravel:	0	D_{10}:	0.08	C_u:	4.75
% Sand:	63	D_{30}:	0.18	C_c:	1.07
% Fines:	37	D_{60}:	0.38		

Figure 7 Particle Distribution Curves for Palm Kernel Shell and Coarse Aggregate

Table 4 Particle Distribution Data for CPKS and FA.

Weight of Container (g):	450.0	Weight of Container & Soil (g):	1000.0
Weight of Dry Sample (g):	550.0	ASTM D422-63(2007)	

Diameter (mm)	Diameter (mm)	Soil Retained FA (g)	Soil Retained CPKS (g)	Soil Retained FA (%)	Soil Retained CPKS (%)	Soil Passing FA (%)	Soil Passing CPKS (%)
19	19	0	0.0	0	0.0	100.0	100.0
12.7	12.7	0	0	0	0.0	100.0	100.0
9.52	9.52	0	0	0	0.0	100.0	100.0
4.75	4.75	0	0	0	0.0	100.0	100.0
2.36	2.36	210	256	21	25.6	79.0	74.4
1.18	1.18	233.5	224.5	23.35	22.5	55.7	52.0
0.6	0.6	199.9	187.5	19.99	18.8	35.7	33.2
0.425	0.425	150	130.9	15	13.1	20.7	20.1
0.3	0.3	100	129.7	10	13.0	10.7	7.1
0.15	0.15	76.5	44.5	7.65	4.4	3.0	2.7
0.075	0.075	30.1	27.0	3.01	2.7	0.0	0.0
PAN	PAN	0	0.0	0	0.0	0.0	0.0
TOTAL:		**1000**	**1000**	**100.00**	100.0		



Grain Size Distribution Curve Results:

% Gravel:	**0**	D_{10}:	**0.08**	C_u:	**4.75**
% Sand:	**63**	D_{30}:	**0.18**	C_c:	**1.07**
% Fines:	**37**	D_{60}:	**0.38**		

Figure 8: Particle Distribution Curves CPKS and FA.

3.2. MARSHAL PROPERTIES OF MODIFIED ASPHALTIC CONCRETE

On Table 5 are test results from the carried out Marshall test on the modified asphaltic concrete. They include stability, flow, and volume of the bitumen (V_b), air void, Volume Filled with Bitumen (VFB), Volume of Mixed Aggregate (VMA) and the density.

Table 5 Marshall Stability and Flow Results

% PKS AND CPKS	Wt. in air (g)	Wt. in water (g)	Density g/cm^3	Vol. of bitumen (V_b)	Stability (Kg)	Flow (mm)	Vv (%)	VMA	VFB (%)
0	1782.5	1107.9	2.64	0.13	2599.5	12	3.7	16.77	84
10	1700.6	1039.4	2.51	0.13	2305.5	9.5	3.98	20.67	79.25
20	1633.3	934.7	2.33	0.14	1157.58	12	4.2	10.46	77.13
30	1502.1	823.6	2.21	0.15	1098.72	8	4.63	10.54	79.01
40	1321.9	712.3	2.16	0.17	1216.44	12.1	5.22	16.31	76.34
50	1233	613	1.98	0.17	1000.62	12	5.62	17.22	78.97

Table 6 Marshall Mix design Specifications[20]

Test Property	Specified Value
Marshal Stability, Kg	340 (minimum)
Flow Value, 0.25mm Units	8 – 17
Percent Air Voids in the Mix Vv %	3 – 5
Voids Filled with Bitumen VFB %	75 – 85

It was observed that on the average as the coarse aggregates were reduced and palm kernel shells added, the Marshall stability reduced while the flow increased. This is to be expected because a reduction in flow implies more strength for the mix. Marshall Stability value of 25.99kN was obtained using granite alone as coarse aggregate and 10.00kN using palm kernel shells up to 50% of the mix as coarse aggregates. This shows a reduction in percentage of up to 57%. Marshall Stability range for road surfaces carrying between 1 and 6000 commercial vehicles per day should be between 2 and 10kN. The implication is that with the proper stress calculation and appropriate thicknesses of underlying layers, even the asphalt concrete with 50% palm kernel shells is suitable for lightly trafficked roads. Since the same amount of bitumen was used, the flow values are almost similar. The increase would have been caused by the weaker bonds created by the palm kernel shells and their high water retention capacity which can mix the bitumen to increase its water content, hence viscosity. Although increases in flow values were noticed, they still fell below the specified range of 5mm maximum.

3.3. Discussion of the ANN model

The performance of the test data set for the developed ANN model was measured statistically by RMSE, MPE and AFV as presented in Table 7. The RMSE, MPE and AFV values obtained are 0.0766, 0.0606 and 0.9986 respectively for density, 0.0082, 0.0009 and 0.9985 respectively for V_b, 0.6001, 0.4107 and 0.9987 respectively for stability, 2.6408, 1.4937 and 0.9462 respectively for flow, 1.6815, 0.1626 and 0.999 respectively for Vv, 4.3853, 2.2343 and 0.9523 respectively for VMA and 1.1388, 0.7177 and 0.9999 respectively for VFB. From these values it could be inferred that the ANN model was able to effectively learn and predict all outputs investigated.

Table 7 Performance measurement of test data

Performance Indicators	Density g/cm^3	Vol of bitumen (vb)	Stability (kN)	Flow (mm)	Vv (%)	VMA	VFB (%)
RMSE	0.0766	0.0082	0.6001	2.6408	0.1682	4.3853	1.1388
MPE	0.0606	0.0009	0.4106	1.4937	0.162	2.2343	0.7176
AFV	0.9986	0.9985	0.9987	0.9462	0.999	0.9523	0.9999

The effect of the input factors on all outputs investigated are displayed by the response surface plots presented in Figures 9 and 10. Figure 9 shows the nonlinear relationship between the % of GPKS and CPKS and between the input variables and output variables. From these response surface plots presented, the density was observed to have reduced with increase in the % of GPKS and CPKS while the effect of weight in air was observed to be negligible. Volume of bitumen was observed to increase with reduced values of weight in air while the effect of % of GPKS and CPKS was observed to be negligible. The effect of both factors on stability seems negligible while for flow, Vv and VFA the weight in air had more effect when compared to the % of GPKS and CPKS. The VFB is increased by reduced values of weight in air and increased % of GPKS and CPKS.

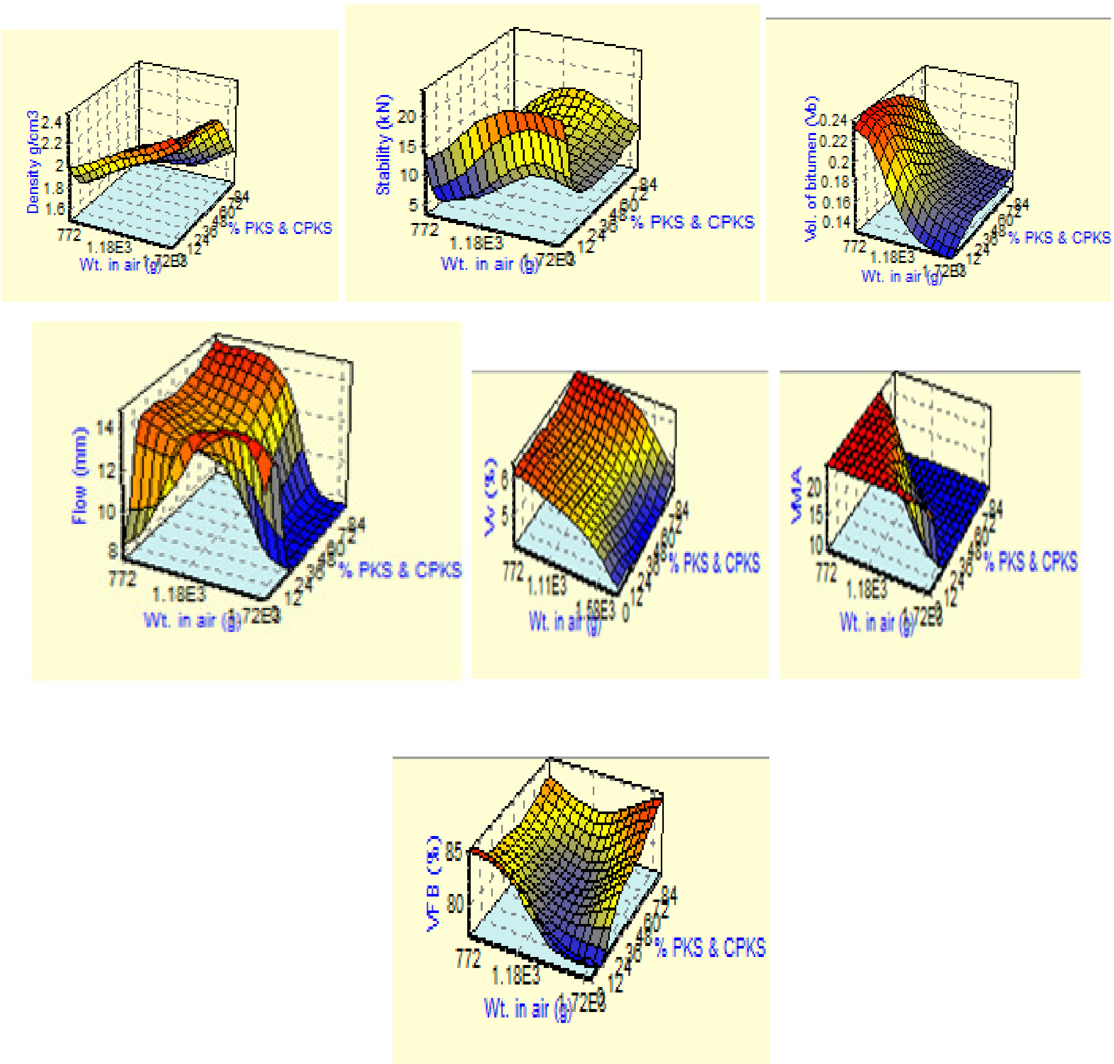


Figure 9: Response surface plots for %GPKS & CPKS and wt. in air for all properties predicted using the QP-ANN.

Figure 10 shows the nonlinear relationship between the % PSK and CPSK and the weight in water, it was observed that the density increased as the weight in water increased and the % PSK and CPSK reduced. The volume of bitumen, Vv and VMB was observed to increase with reduced weight in water while the effect of varying % PSK and CPSK seemed negligible. Stability and flow tended to increase with increase in weight in air while the effect of varying % PSK and CPSK seemed negligible.

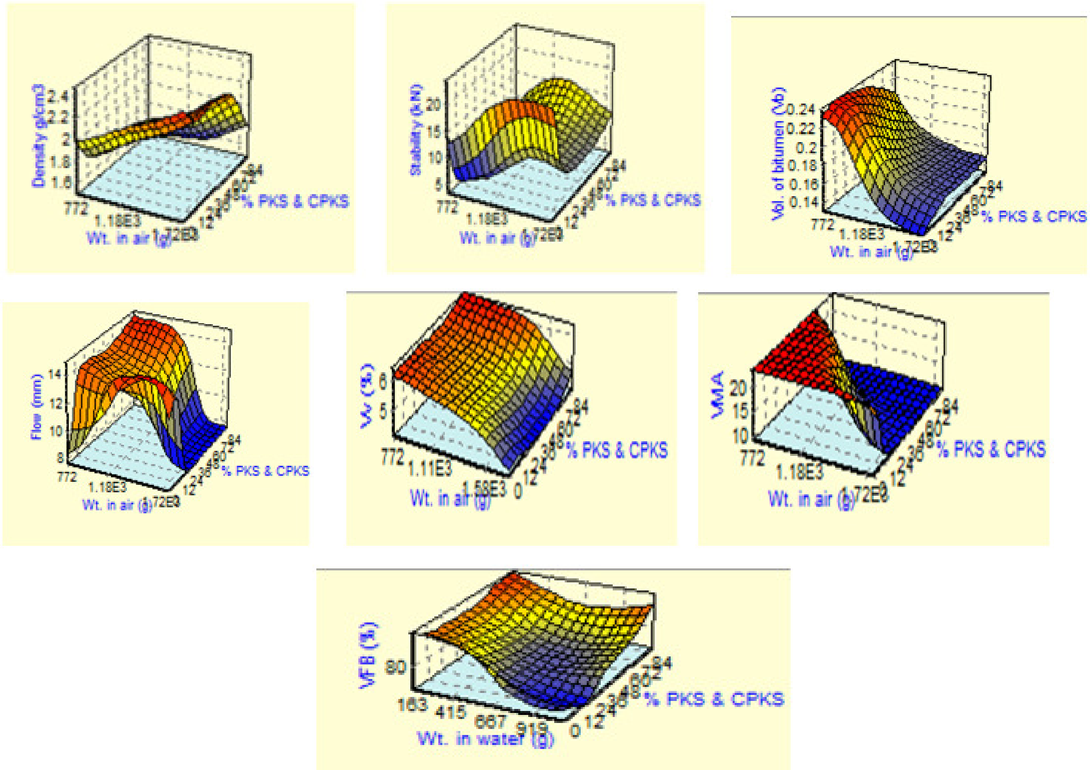


Figure 10: Response surface plots for %PKS & CPKS and wt. in water for all properties predicted using the QP-ANN.

The contribution of each input variable to the output variables is presented in Figure 11.

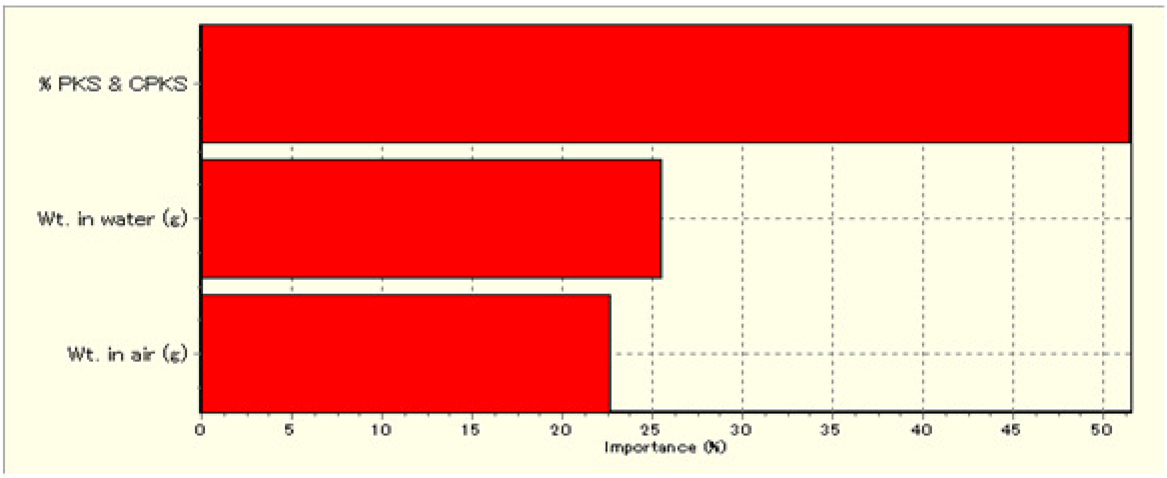


Figure 11 Contribution of input variables

From this, it can be inferred that the % PSK and CPSK had the most significant contribution followed by the weight in water and lastly weight in air. In addition, Table 8 presents the optimization of the experimental data using the optimal algorithm search approach available in Genetic Algorithm (GA). The GA consist of a population size of thirty (30), cross over rate of 0.8, mutation rate of 0.1, absolute top mate selection type and uniform crossover type. From the optimization process it was observed that for maximum output (Density, Stability, Flow, volume of bitumen, Vv, VMA and VFB) the quantity for input factors (% PKS and CPKS, weight in air and weight in water) should be 1.207319, 772.4272 and 1029.493 respectively.

Table 8 Optimization process by optimal algorithm

Parameter	Output
Density g/cm3	2.091878
Vol. of bitumen (Vb)	0.180208
Stability (kN)	24.15669
Flow (mm)	14.90384
Vv (%)	6.156592
VMA	23.855
VFB (%)	82.71007
Parameter	Input
% PKS & CPKS	1.207319
Wt. in air (g)	772.4272
Wt. in water (g)	1029.493

4. CONCLUSION

This research has evaluated the effect of partial replacement of conventional aggregates with PKS and CPKS on the Mechanical, Marshall and Volumetric properties of bituminous mixture using artificial neural network. From the results obtained, the following conclusion were drawn:

- Palm kernel shells can be used as partial replacement for coarse aggregate up to 10% for heavily trafficked roads and 50% for lightly trafficked roads.
- For the very lightly trafficked roads in the rural communities, palm kernel shells can be used as full replacement for the coarse aggregates. This will go a long way into reducing construction and maintenance costs of these roads.
- The quest by governments in developing countries, especially those in Africa, south of the Sahara for use of locally available materials in infrastructure development will be met with the use of palm kernel shells as a road construction material.
- Artificial Neural Network is a powerful tool for forecasting the behaviour of the properties of an asphaltic concrete mix either in a virgin or modified form. In this case, it has successfully described the effect of partial replacement of natural aggregates with PKS and CPKS on the Marshal and volumetric properties of the resultant modified mix. The proportion of PKS and CPKS had the most significant contribution or influence on the properties of modified mix, followed by weight in water and lastly weight in air.
- The economic power of rural dwellers will be enhanced if they are encouraged to plant palm trees from which these shells could be gotten.
- Graded palm kernel shell can be used for asphalt concrete production for low to medium traffic roads and through the use of palm kernel shells in road construction materials, the environmental hazards associated with complete dependence on conventional materials can be minimized.

- Finally, the cost of road construction and maintenance can be greatly minimized through the use of alternative agricultural waste products (palm kernel shell) for road construction materials.

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