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Study of the Performance of Graded Palm Kernel Shells (PKS) As Partial Replacement for Coarse Aggregates in Hot Mix Asphalt (HMA) Binder Course with Zycotherm Chemical Additive

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Abstract: *The study looked at the potentials of palm kernel shells as coarse aggregates in an asphalt binder course using bitumen modified with zycotherm chemical additive. It also tries to investigate the effects of the modifier on asphalt concrete. All the volumetric and physical properties of the asphalt mixtures were evaluated using Marshall Mix design procedures. PKS percentage rates used were 0%, 25%, 50%, 75% and 100% by weight of the total coarse aggregate size at 4 – 8mm. Seventy five (75) test samples of compacted asphalt mix were prepared, 15 samples for the control mix and 60 samples for the PKS portions. The samples were prepared by varying bitumen contents from 4.5% – 6.5% of the weight of the total aggregate weights used. The observed results show that at optimum binder contents (OBC), with zycotherm chemical additive, 75% and 100% replacement could be used for light – heavily Trafficked roads. However, 25% and 50% replacements could be used for light traffic situations as VFB values observed at optimum binder contents were slightly above recommended limits. From the results observed, it could be established that PKS is a viable agricultural waste product that could be used in road constructions as replacement of coarse aggregate in binder courses. When comparisons were made with asphalt concretes produced with the modified bitumen and plain bitumen, results showed that the zycotherm chemical additive positively affects asphalt concrete as improvements were seen in volumetric and physical properties. The result comparisons showed Marshall Stability, flow and void characteristics (Va, VMA, and VFB) were all improved as bitumen content required was lowered for the same mix design proportion and compaction load compared. This could be cost effective on the long run.*

Keywords: *Marshall Mix Design, Palm Kernel Shells, Binder Course, Coarse Aggregates, Zycotherm Chemical Additive.*

I. INTRODUCTION

As developing nations worldwide strive for economic growth, sustainability and stability as well as to close the gap on the developed nations in terms of infrastructural innovations and development, efforts should be geared towards innovative developments and eco-friendly and economically viable ideas. One of such ideas is the re-use of by-product of domestic, mining and industrial activities. Recent developments in technologies and researches have continued to prove that there are several successful ways to make use of these so called wastes or by-products. One of these solutions is to use them in road construction as aggregates to replace or partially replace conventional materials. In the same light, the practice of modifying asphalt binders have been thought to offer improved performances over conventional binders and as such improve asphaltic mixtures for better performances of asphaltic paving surfaces.

The road construction industry depends majorly on conventional materials such as asphalt cement, granite, sand and fillers for the production of asphalt concrete. The costly nature of these materials have greatly hindered the course of development of road pavements in the country, herein lies the need for engineering considerations on available cheaper materials to invariably reduce construction costs for growth and development. Research studies in material sciences and engineering continually prove the potentials of having local materials to partially and fully replace these costly conventional ones. Historically, agricultural and industrial wastes have created waste management and pollution problems. However the use of agricultural wastes to complement other traditional materials in construction provides both practical and economic advantages.

Research studies have been thoroughly carried out using PKS; these include studies and investigations in soil compaction and stabilization, to using PKS as a viable source of coarse aggregate in structural concrete mostly in the production of light weight concrete and a few studies on its use also as aggregates (coarse and fines) in bituminous or asphalt concrete works. Researches were also conducted on the viability of crushed PKS as fine aggregates. Mohammed et al (2014), carried out research were to this effect. They studied the potential of crushed palm kernel shells as partial replacements of fine aggregate in asphalt concrete. The results obtained showed that the samples with 10 and 50% partial replacement of fine aggregate (sand) with crushed palm kernel shell were within the specifications for asphalt concrete roads.

In investigative studies carried out by Olutaiwo and Owolabi (2015) on the effects of partial replacement of coarse aggregate with graded palm kernel shells in asphalt binder course at varying percentages of PKS content rates by weight of total coarse aggregate size of 4- 8mm. Marshall tests conducted established that PKS was a viable agricultural waste product that could be used as coarse aggregate at a specific percentage in the production of asphaltic binder courses for light to medium trafficked roads. Ndoke (2006) also investigated the potential of palm kernel shells as coarse aggregate in road binder course with emphasis on strength of the asphalt concrete as given by the Marshall Stability and flow values. In the study, it was observed that palm kernel shells could be used to replace coarse aggregate up to 10% for heavily Trafficked roads and 100% replacement was possible for light trafficked roads in rural areas.

Modifying bituminous materials can bring real benefits to highway maintenance and construction, in terms of better and long lasting roads and savings in total road life [Mangesh et al (2012)]. Harish and Shirakumar (2013) investigated the effects of modifying bituminous concrete with crumb rubber and waste shredded thermo-plastics and significant improvements in properties like Marshall stability, retained stability, indirect tensile strength where observed in comparison with conventional mix. Bamidele et al (2013) in their investigative research study on the use of shredded PWS (pure water sachets) to modify bitumen at various percentages weight of bitumen observed increases in viscosity decreasing penetration with subsequent increase in PWS while the values of the softening point increased with respect to increase in PWS. Ashik Bellary and Lokesh Gupta (2016) in there research publication on the use of GGBS as filler and zycotherm as chemical additive (0.1% weight of asphalt/bitumen) for a bituminous concrete mixture observed satisfactory test results as regards standard MORT&H specifications which is in line with asphalt institute standards. Likewise, Rohith n and J.Ranjitha (2013) on their study publication on the Marshall Stability properties of warm mix asphalt using zycotherm as a chemical additive also concluded that stability & Marshall Properties were improved for the wma mix by the addition of the additive.

II. MATERIALS AND METHODS

The typical materials which constituted the asphalt concrete where stone dust (0-5 mm), river sand (0-4 mm) and crushed stone of size ranges of 4-8 mm, 8-16 mm and 16-24 mm. These where all obtained from Julius Berger Construction Company Stockpiles at Apapa in Lagos state Nigeria. The palm kernel shells used in the aggregate replacement were obtained locally from Badagry market also in Lagos state south west of Nigeria. Bitumen of 60/70 penetration grade modified with zycotherm chemical additive was used in the test study. This was used to produce the entire test specimens. The bitumen was supplied by Julius Berger construction company which was modified with zycotherm chemical additive supplied by VXL limited (Zycosoil) Ilupeju Lagos state specified percentage proportions of the samples used for combined gradation in the production of the asphalt concrete for the binder course was carried out as follows: 35% stone dust (0-5 mm), 7% river sand (0-4 mm), 10% crushed stone (size 4-8 mm), 15% crushed stone (size 8-16 mm) and 33% crushed stone (size 16-24 mm) with bitumen content between 4.5% and 6.5% at varying increments of 0.5%. The PKS aggregate samples were varied between 25%, 50%, 75% and 100% partial to full replacement of coarse aggregate (size 4-8 mm).

Blending was done at a temperature of 145- 160ºc and allowed to reduce to a temperature of 145ºc before it was compacted on the both sides with 50 blows to obtain cylindrical samples. Marshall Stability and flow tests were carried out at a temperature of 60ºc on the samples. Other tests carried out include specific gravity tests, asphalt content determination by solvent extraction and aggregate gradation tests. Preliminary tests were carried out on both the aggregates to be used as well as the zycotherm modified bitumen used. Test results could be seen in the tables below.

Table 1: Mix Proportion in Percent with Specific Gravities of the Aggregates Used

Aggregate Sizes Used	Mix Proportion (%)	Specific Gravity
16mm – 24mm Crushed Stone	33	2.760
8mm – 16mm Crushed Stone	15	2.677
4mm – 8mm Crushed Stone	10	2.670
0 – 5mm Stone Dust	35	2.600
0 – 4mm River Sand	7	2.665
PKS	VARIED	1.620

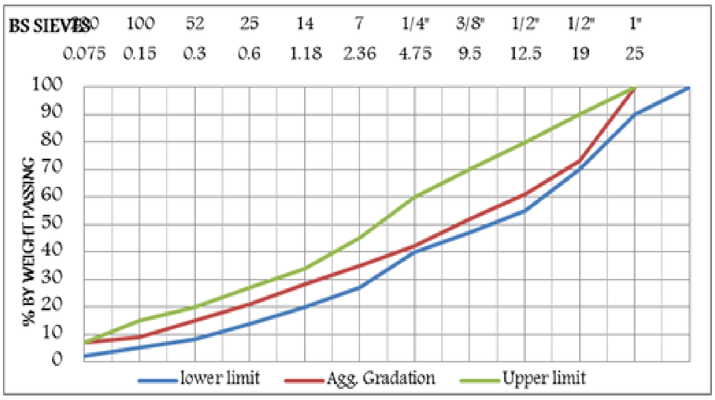
Courtesy: Julius Berger Company Asphalt Labs

Table 2: Some Properties of the Modified Bitumen Used

Asphalt Property	Test Results	Specifications
Specific Gravity At 25ºc	1.04	≥ 1
Softening Point (Ball & Ring) ºc	51	> 50ºc
Penetration At 25ºc - 0.1mm	66	60 - 70
Solubility In Trichloroethylene % By Weight	99	99

III. TEST RESULTS AND DISCUSSION

3.1 Aggregate Gradation Analysis



Sieve	%
BS	Passing
31.75	-
25	100
19	73
12.5	61
9.5	52
4.75	42
2.36	35
1.18	28
0.6	21
0.3	15
0.15	9
0.075	7

Fig.1: Sample Of Binder Course Aggregate Gradation Envelope 5.5% Binder Content (75%PKS)

Note: Other Aggregate Gradations At 0%, 25%, 75% And 100% PKS Replacement Rates Were Derived and All Were Within the Gradation Envelope According To Binder Course Requirements of FMWH General Specification for Roads and Bridges (1994).

3.2 Marshall Test Results and Analysis

Table 3: Marshall Properties of Hot Mix Asphalt Prepared Using Zycotherm And 0% PKS Replacement as Coarse Aggregate Material (4-8mm)

Binder Content (%)	Unit Weight (g/ml)	Marshall Stability(KN)	Flow (mm)	Total Air Voids (Va) (%)	Voids Filled With Bitumen (VFB) (%)	Voids In Mineral Aggregate (VMA) (%)
4.5	2.293	12.83	3.53	5.40	64.75	15.32
5.0	2.301	13.97	3.73	4.80	69.74	15.86
5.5	2.351	15.32	3.77	4.08	75.29	16.51
6.0	2.331	14.47	4.01	2.79	82.82	16.24
6.5	2.282	13.38	4.06	2.44	85.39	16.70

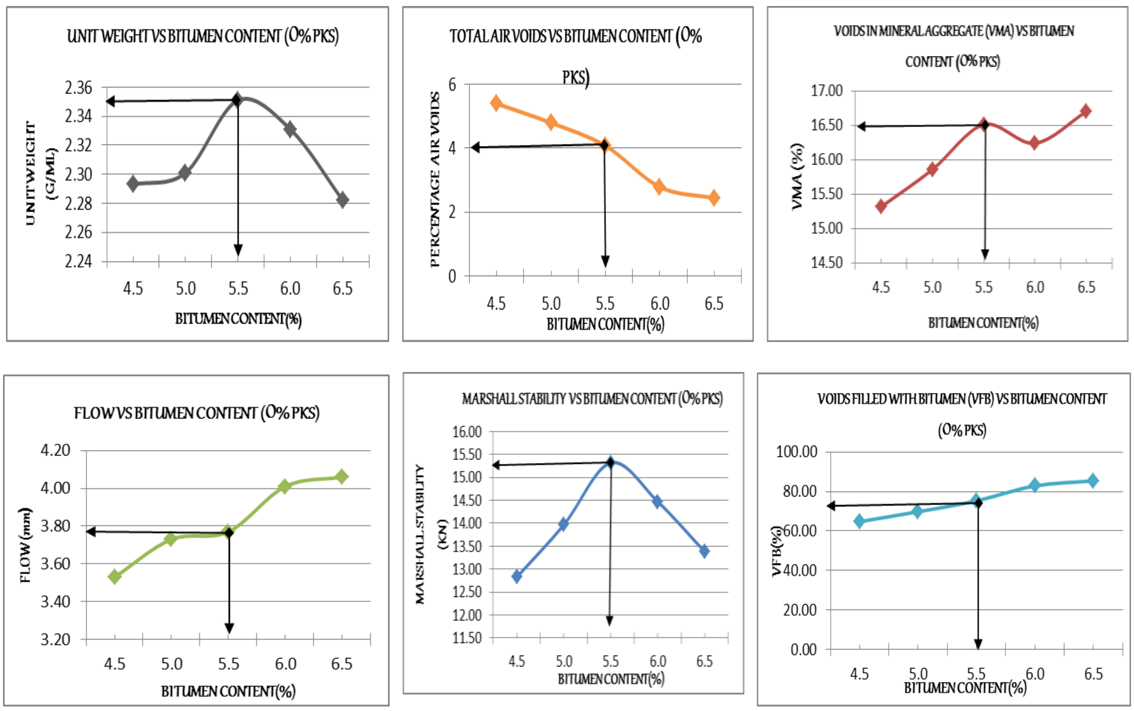


Fig. 2: Marshall Properties of Hot Mix Asphalt Prepared Using Zycotherm And 0% PKS Partial Replacement as Coarse Aggregate Material (4-8mm)

Table 4: The Optimum Binder Content Value At 0% PKS Replacement

	PROPERTIES		
	Max Unit Weight	Max. Stability	Median Of Percent Air Voids(4% Air Void)
BINDER CONTENT (%)	5.50	5.50	5.55

Average Value = 5.52%
Therefore, Optimum Binder Content (OBC) At 0% PKS Replacement = 5.52%

Table 5: Properties At 5.5%Approx. Optimum Binder Content At 0% PKS Replacement

PROPERTIES	**VALUES**	**SPECIFICATION**	**REMARKS**
Stability(KN)	15.32	Not Less Than 3.5	Satisfactory
Flow(mm)	3.77	2 – 6	Satisfactory
Va (%)	4.00	3 – 5	Satisfactory
VFB (%)	75.29	65 – 78	Satisfactory
OBC (%)	5.5	4.5 - 6.5	Satisfactory
VMA (%)	16.51	MINIMUM OF 13%	Satisfactory

Table 6: Marshall Properties of Hot Mix Asphalt Prepared Using Zycotherm And 25% PKS Replacement as Coarse Aggregate Material (4-8mm)

Binder Content (%)	Unit Weight (g/ml)	Marshall Stability(KN)	Flow (mm)	Total Air Voids (Va) (%)	Voids Filled With Bitumen (VFB) (%)	Voids In Mineral Aggregate (VMA) (%)
4.5	2.229	10.72	3.46	5.35	64.33	15.00
5.0	2.279	11.17	3.58	5.04	68.50	16.00
5.5	2.278	12.54	3.32	5.48	68.74	17.53
6.0	2.317	12.62	3.78	2.98	81.77	16.35
6.5	2.316	12.14	3.98	3.02	82.74	17.50

Table 7: The Optimum Binder Content Value At 25% PKS Replacement

	PROPERTIES		
	Max Unit Weight	Max. Stability	Median Of Percent Air Voids(4% Air Void)
BINDER CONTENT (%)	6.0	6.0	5.75

Average Value = 5.92%
Therefore, Optimum Binder Content (OBC) At 25% PKS Replacement = 5.92%

Table 8: Properties At 5.9%Approx. Optimum Binder Content At 25% PKS Replacement

PROPERTIES	**VALUES**	**SPECIFICATION**	**REMARKS**
Stability(KN)	12.52	Not Less Than 3.5	Satisfactory
Flow(mm)	3.79	2 – 6	Satisfactory
Va (%)	3.15	3 – 5	Satisfactory
VFB (%)	79.25	65 – 78	Not Satisfactory
OBC (%)	5.92	4.5 - 6.5	Satisfactory
VMA (%)	16.40	MINIMUM OF 13%	Satisfactory

Table 9: Marshall Properties of Hot Mix Asphalt Prepared Using Zycotherm And 50% PKS Partial Replacement as Coarse Aggregate Material (4-8mm)

Binder Content (%)	Unit Weight (g/ml)	Marshall Stability(KN)	Flow (mm)	Total Air Voids (Va) (%)	Voids Filled With Bitumen (VFB) (%)	Voids In Mineral Aggregate (VMA) (%)
4.5	2.202	10.81	3.67	6.18	61.59	16.09
5.0	2.202	10.98	3.74	7.56	58.35	18.15
5.5	2.218	11.59	4.00	3.44	77.32	15.17
6.0	2.222	11.94	3.99	3.10	80.53	15.92
6.5	2.249	11.56	4.01	2.34	85.73	16.40

Table 10: The Optimum Binder Content Value At 50% PKS Replacement

	PROPERTIES		
	Max Unit Weight	Max. Stability	Median Of Percent Air Voids(4% Air Void)
BINDER CONTENT (%)	6.5	6.0	5.48

Average Value = 5.99%
Therefore, Optimum Binder Content (OBC) At 50% PKS Replacement = 5.99%

Table 11: Properties At 6.0%Approx. Optimum Binder Content At 50% PKS Replacement

PROPERTIES	**VALUES**	**SPECIFICATION**	**REMARKS**
Stability(KN)	11.94	Not Less Than 3.5	Satisfactory
Flow(mm)	3.99	2 – 6	Satisfactory

Va (%)	3.10	3 – 5	Satisfactory
VFB (%)	80.03	65 – 78	Not Satisfactory
OBC (%)	5.99	4.5 - 6.5	Satisfactory
VMA (%)	15.92	MINIMUM OF 13%	Satisfactory

Table 12: Marshall Properties of Hot Mix Asphalt Prepared Using Zycotherm And 75% PKS Partial Replacement as Coarse Aggregate Material (4-8mm)

Binder Content (%)	Unit Weight (g/ml)	Marshall Stability(KN)	Flow (mm)	Total Air Voids (Va) (%)	Voids Filled With Bitumen (VFB) (%)	Voids In Mineral Aggregate (VMA) (%)
4.5	2.085	10.39	3.38	3.96	69.49	12.98
5.0	2.103	9.92	3.62	4.41	69.63	14.52
5.5	2.123	10.40	3.83	5.05	68.98	16.28
6.0	2.143	11.07	3.88	2.15	85.18	14.51
6.5	2.109	10.49	3.78	3.70	78.08	16.88

Table 13: The Optimum Binder Content Value At 75% PKS Replacement

	PROPERTIES		
	Max Unit Weight	Max. Stability	Median Of Percent Air Voids(4% Air Void)
BINDER CONTENT (%)	6.5	6.0	4.55

Average Value = 5.52%
Therefore, Optimum Binder Content (OBC) At 75% PKS Replacement = 5.52%

Table 14: Properties At 5.5%Approx. Optimum Binder Content At 75% PKS Replacement

PROPERTIES	**VALUES**	**SPECIFICATION**	**REMARKS**
Stability(KN)	10.40	Not Less Than 3.5	Satisfactory
Flow(mm)	3.83	2 – 6	Satisfactory
Va (%)	4.99	3 – 5	Satisfactory
VFB (%)	68.98	65 – 78	Satisfactory
OBC (%)	5.52	4.5 - 6.5	Satisfactory
VMA (%)	15.00	MINIMUM OF 13%	Satisfactory

Table 15: Marshall Properties of hot mix asphalt prepared using zycotherm and 100% PKS Partial Replacement as Coarse Aggregate Material (4-8mm)

Binder Content (%)	Unit Weight (g/ml)	Marshall Stability(KN)	Flow (mm)	Total Air Voids (Va) (%)	Voids Filled With Bitumen (VFB) (%)	Voids In Mineral Aggregate (VMA) (%)
4.5	2.126	9.84	3.78	5.97	60.65	15.17
5.0	2.114	10.03	3.74	6.95	59.38	17.11
5.5	2.101	10.09	3.71	4.15	72.81	15.26
6.0	2.080	9.75	3.60	4.46	72.90	16.46
6.5	2.118	9.82	3.59	2.53	83.96	15.77

Table 16: The Optimum Binder Content Value At 100% PKS Replacement

	PROPERTIES		
	Max Unit Weight	Max. Stability	Median Of Percent Air Voids(4% Air Void)
BINDER CONTENT (%)	4.5	5.5	5.5

Average Value = 5.27%
Therefore, Optimum Binder Content (OBC) At 100% PKS Replacement = 5.27%

Table 17: Properties At 5.3%Approx. Optimum Binder Content At 100% PKS Replacement

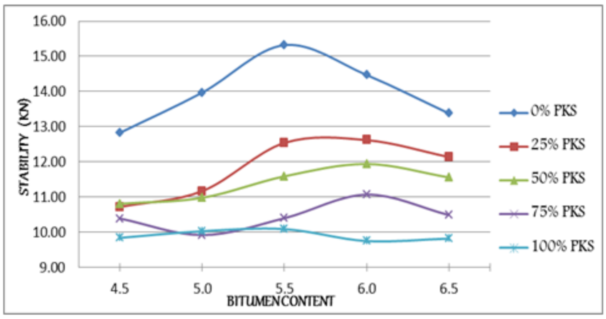
PROPERTIES	**VALUES**	**SPECIFICATION**	**REMARKS**
Stability(KN)	10.07	Not Less Than 3.5	Satisfactory
Flow(mm)	3.70	2 – 6	Satisfactory
Va (%)	5.00	3 – 5	Satisfactory
VFB (%)	70.00	65 – 78	Satisfactory
OBC (%)	5.27	4.5 - 6.5	Satisfactory
VMA (%)	16.00	MINIMUM OF 13%	Satisfactory

Table 18: Comparisons Of Properties At Mix Proportions Of PKS Replacement

PROPERTIES	**0%**	**25%**	**50%**	**75%**	**100%**	**SPECIFICATION**
Stability(KN)	15.32	12.52	11.94	10.40	10.07	Not Less Than 3.5
Flow(mm)	3.77	3.79	3.99	3.83	3.70	2 – 6
Va (%)	4.00	3.15	3.10	4.99	5.00	3 – 5
VFB (%)	75.29	79.25	80.03	68.98	70.00	65 – 78
OBC (%)	5.5	5.92	5.99	5.52	5.27	4.5 - 6.5
VMA (%)	16.51	16.40	15.92	15.00	16.00	MINIMUM OF 13%

Table 19: Marshall Stability Parameter Variation From 0% - 100% PKS Replacement

BINDER CONTENT (%)	0%	25%	50%	75%	100%	SPECIFICATION		
4.5	12.83	10.72	10.81	10.39	9.84	LIGHT TRAFFIC (< 10^4 ESALS) MIN. 3.5KN	MEDIUM TRAFFIC (10^4 – 10^6 ESALS) MIN. 6.0KN	HEAVY TRAFFIC (> 10^6 ESALS) MIN. 9.0KN
5.0	13.97	11.17	10.98	9.92	10.03			
5.5	15.32	12.54	11.59	10.40	10.09			
6.0	14.47	12.62	11.94	11.07	9.75			
6.5	13.38	12.14	11.56	10.49	9.82			



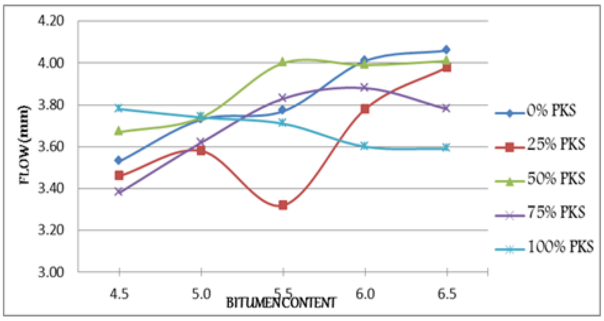
It is observed that there is decrease in stability from 0% to 100% mix proportions of PKS replacement. Stability has peak value of 15.32KN at 5.5BC% of 0% PKS replacement. Stability has lowest value of 9.82KN at 6.5BC% of 100% PKS replacement. The trend shows about 35% reduction in stability but the lowest value obtained is still within the specified limit

Fig. 3: Graph of Marshall Stability Variations From 0% To 100% PKS Replacement

Table 20: Marshall Flow Parameter Variations From 0% - 100% PKS Replacement

BINDER CONTENT (%)	0%	25%	50%	75%	100%	SPECIFICATION
4.5	3.53	3.46	3.67	3.38	3.78	**(2 Mm – 4 Mm)**
5.0	3.73	3.58	3.74	3.62	3.74	
5.5	3.77	3.32	4.00	3.83	3.71	
6.0	4.10	3.78	3.99	3.88	3.60	
6.5	4.06	3.98	4.02	3.78	3.59	

(Note: Results Obtained Not Within Limits Are In Red)

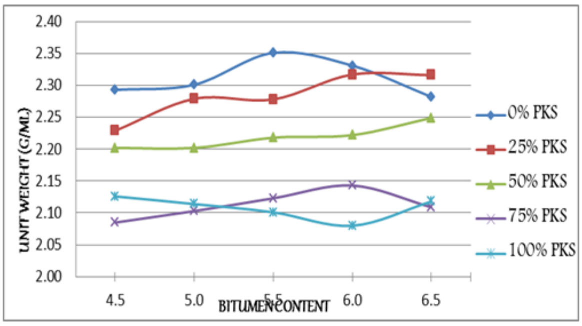


The highest Marshall flow was 4.06mm at 6.5BC of 0% PKS and the least was 3.32mm at 5.5BC of 25%PKS. All flow parameters were within specified limits for all varying rates of PKS replacement except for marginal increases in 50% PKS and 0%PKS.

Fig. 4: Graph of Marshall Flow Variations From 0% To 100% PKS Replacement

Table 21: Unit Weight Parameter Variations From 0% - 100% Pks Replacement

BINDER CONTENT (%)	0%	25%	50%	75%	100%	SPECIFICATION
4.5	2.293	2.229	2.202	2.085	2.126	N/A
5.0	2.301	2.279	2.202	2.103	2.114	
5.5	2.351	2.278	2.218	2.123	2.101	
6.0	2.331	2.317	2.222	2.143	2.080	
6.5	2.282	2.316	2.249	2.109	2.118	



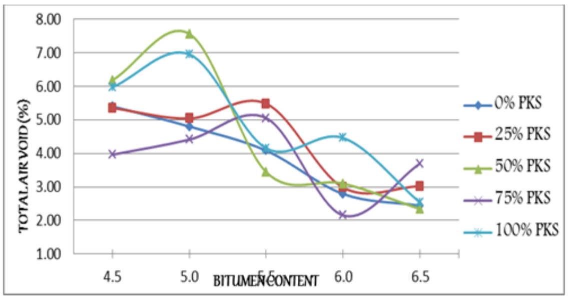
It is observed as expected that there was decrease in the unit weight from 0% to 100% mix proportions of PKS replacement. This is as a result of the lower specific density of Palm kernel shells.

Fig. 5: Graph of Unit Weight Variations From 0% To 100% PKS Replacement

Table 22: Percentage Air Void (Va) Parameter Variation From 0% - 100% PKS Replacement

BINDER CONTENT (%)	0%	25%	50%	75%	100%	SPECIFICATION
4.5	5.40	5.35	6.18	3.96	5.97	**3 – 5 %**
5.0	4.80	5.04	7.56	4.41	6.95	
5.5	4.08	5.48	3.44	5.05	4.15	
6.0	2.79	2.98	3.10	2.15	4.46	
6.5	2.44	3.02	2.34	3.70	2.53	

(Note: Results Obtained Not Within Limits Are In Red)



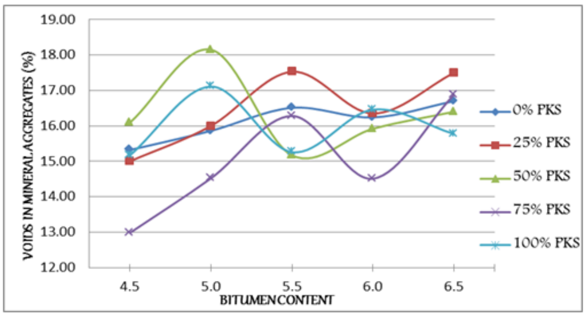
The air voids seemed to reduce with increase in binder content across all varying rates. Highest value is at 5.0%BC of 50% PKS whereas the least value was at 6.0%BC 0f 75% PKS

Fig. 6: Graph of Air Void (%) Variations From 0% To 100% PKS Replacement

TABLE 23: Voids In Mineral Aggregates (VMA) Variations From 0% - 100% PKS Replacement

BINDER CONTENT (%)	0%	25%	50%	75%	100%	SPECIFICATION
4.5	15.32	15.00	16.09	12.98	15.17	MINIMUM OF 13%
5.0	15.86	16.00	18.15	14.52	17.11	
5.5	16.51	17.53	15.17	16.28	15.26	
6.0	16.24	16.35	15.92	14.51	16.46	
6.5	16.70	17.50	16.40	16.88	15.77	

(Note: Results Obtained Not Within Limits Are In Red)

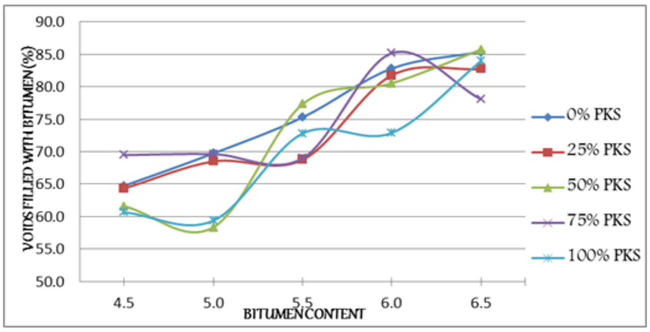


Highest VMA result of 18.15% was at 5.0% **BC** at 50% PKS replacement, whereas the minimum result of 14.52% is at 6.0% **BC** at 75% PKS replacement.

Fig. 7: Voids in Mineral Aggregates (%) Variations From 0% To 100% PKS Replacement

Table 24: Voids Filled With Bitumen (VFB) Variation From 0% - 100% PKS Replacement

BINDER CONTENT (%)	0%	25%	50%	75%	100%	SPECIFICATION		
4.5	64.75	64.33	61.59	69.49	60.65	LIGHT	MEDIUM	HEAVY
5.0	69.74	68.50	58.35	69.63	59.38	TRAFFIC	TRAFFIC	TRAFFIC
5.5	75.29	68.74	77.32	68.98	72.81	(< 10^4	(10^4 – 10^6	(> 10^6
6.0	82.82	81.77	80.53	85.18	72.90	ESALS)	ESALS)	ESALS)
6.5	85.39	82.74	85.73	78.08	83.96	70 - 80	65 - 78	65- 75



It is generally observed that with increasing asphalt contents, there is increase in voids filled with bitumen (VFB) throughout the various PKS rates.

Fig. 8: Voids Filled With Bitumen (%) Variations From 0% To 100% PKS Replacement

Table 25: Comparison of Some Asphalt Properties of the Zycotherm Modified Bitumen and Plain Bitumen.

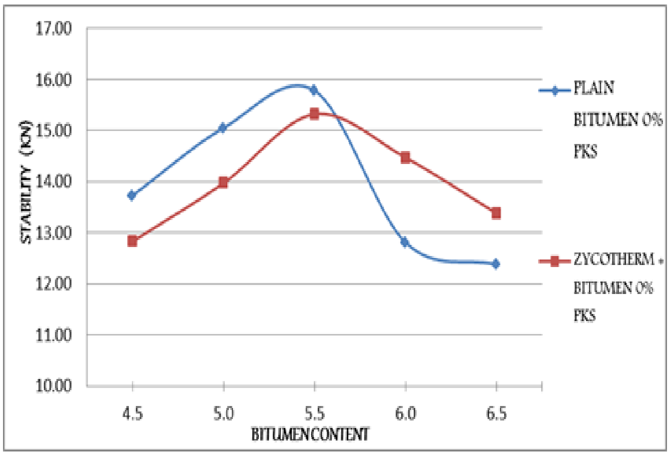
ASPHALT PROPERTY	PLAIN BITUMEN	ZYCOTHERM MODIFIED BITUMEN	SPECIFICATIONS
Specific Gravity At 25°c	1.03	1.04	≥ 1
Softening Point (Ball & Ring) °c	52	51	> 50°c
Penetration At 25C - 0.1mm	60/70	60/70	60 - 70
Solubility In Trichloroethylene % By Weight	99	99	99

Table 26: Comparisons of Asphalt Concrete Marshall Properties of Zycotherm Modified Bitumen and the Plain Bitumen (0% PKS Replacement) At OBC.

PROPERTIES	PLAIN BITUMEN (0%PKS)	ZYCOTHERM MODIFIED BITUMEN (0%PKS)	SPECIFICATION
STABILITY(KN)	14.59	15.32	MINIMUM OF 3.5
FLOW(Mm)	3.64	3.77	2 – 4
VA (%)	5.70	4.00	3 – 5
VFB (%)	69.9	75.29	65 – 78
OBC (%)	5.70	5.52	4.5 - 6.5
VMA (%)	18.70	16.51	MINIMUM OF 13%

Table 27: Comparison of Asphalt Concrete Marshall Stability of Zycotherm Modified Bitumen and the Plain Bitumen At 0% PKS Replacement

	MARSHALL STABILITY OBTAINED IN (KN)				
BINDER CONTENT (%)	PLAIN BITUMEN (0%PKS)	ZYCOTHERM MODIFIED BITUMEN (0%PKS)	SPECIFICATION		
4.5	13.73	12.83	LIGHT TRAFFIC (< 10^4 ESALS) MIN. 3.5KN	MEDIUM TRAFFIC (10^4 – 10^6 ESALS) MIN. 6.0KN	HEAVY TRAFFIC (> 10^6 ESALS) MIN. 9.0KN
5.0	15.05	13.97			
5.5	15.78	15.32			
6.0	12.81	14.47			
6.5	12.38	13.38			



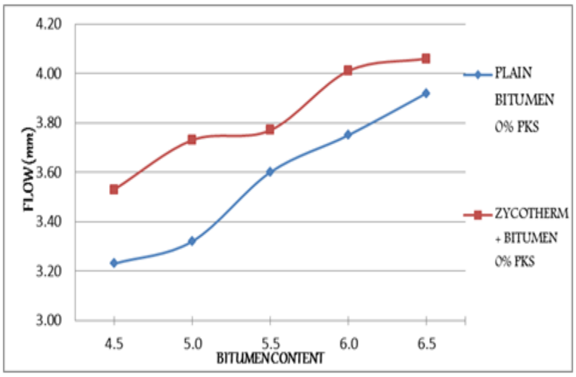
It was however observed that between 4.5% - 5.5% BC, Marshall Stability was slightly higher with the plain bitumen. For 6.0 and 6.5% BC the stability values were much higher with the zycotherm modified bitumen. All stability results obtained were well over the required standard limits.

Fig. 9: Graph of Stability (KN) Variations between the Plain and Zycotherm Modified Bitumen

Table 28: Comparison of Asphalt Concrete Marshall Flow of Zycotherm Modified Bitumen and Plain Bitumen At 0% PKS Replacement

	MARSHALL FLOW STABILITY OBTAINED IN (Mm)		
BINDER CONTENT (%)	PLAIN BITUMEN (0%PKS)	ZYCOTHERM MODIFIED BITUMEN (0%PKS)	SPECIFICATION
4.5	3.23	3.53	2 – 4 (Mm)
5.0	3.32	3.73	
5.5	3.60	3.77	
6.0	3.75	4.01	
6.5	3.92	4.06	

(Note: Results Obtained Not Within Limits Are In Red)



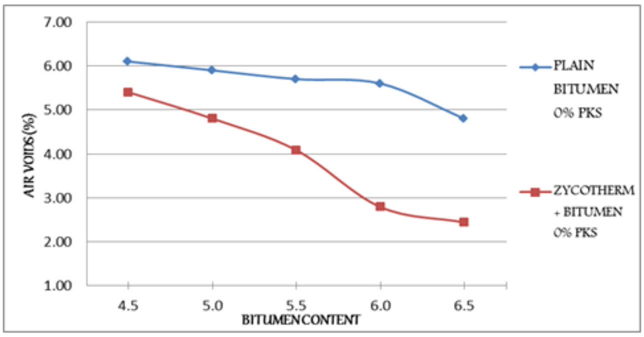
The result showed higher flow rates from the zycotherm modified bitumen more than that of the Plain bitumen across all the various binder content percentages.

Fig. 10: Graph of Flow (mm) Variations between the Plain and Zycotherm Modified Bitumen

TABLE-29: Comparison of Asphalt Concrete Marshall Air Voids of Zycotherm Modified Bitumen and Plain Bitumen At 0% PKS Replacement

	TOTAL AIR VOIDS(VA) PERCENT OBTAINED		
BINDER CONTENT (%)	**PLAIN BITUMEN (0%PKS)**	**ZYCOTHERM MODIFIED BITUMEN (0%PKS)**	**SPECIFICATION**
4.5	6.1	5.40	**3 – 5 (%)**
5.0	5.9	4.80	
5.5	5.7	4.08	
6.0	5.6	2.79	
6.5	4.8	2.44	

(Note: Results Obtained Not Within Limits Are In Red)

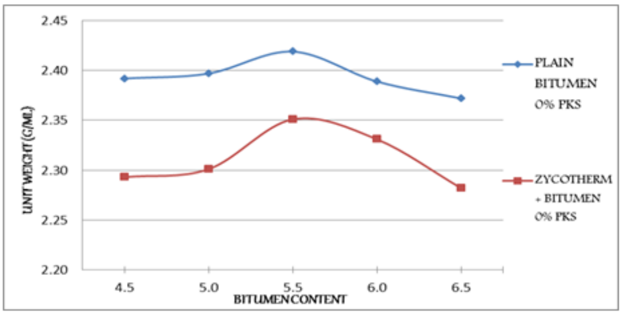


The results obtained shows reductions in percent air void in the zycotherm modified bitumen with regards to the plain bitumen results.

Fig. 11: Graph of Air Void (%) Variations between the Plain and Zycotherm Modified Bitumen

TABLE- 30: Comparison of Asphalt Concrete Marshall Unit Weight (g/ml) Of Zycotherm Modified Bitumen and Plain Bitumen At 0% PKS Replacement

	UNIT WEIGHT (G/ML) OBTAINED		
BINDER CONTENT (%)	**PLAIN BITUMEN (0%PKS)**	**ZYCOTHERM MODIFIED BITUMEN (0%PKS)**	**SPECIFICATION**
4.5	2.392	2.293	N/A
5.0	2.397	2.301	
5.5	2.419	2.351	
6.0	2.389	2.331	
6.5	2.372	2.282	

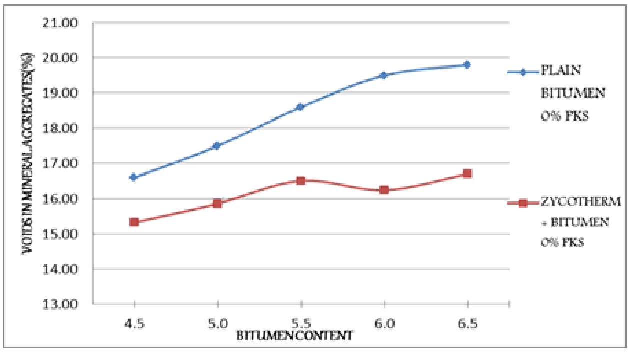


The results show a decrease in the unit weight, with the unit weight obtained using the plain bitumen were relatively higher than the values obtained from the modified bitumen. This is because the zycotherm additive forms a coating on the aggregates reducing water and air absorption rates hence reducing unit weights of compacted samples.

Fig. 12: Graph of Unit Weight (g/ml) Variations between the Plain and Zycotherm Modified Bitumen

TABLE-31: Comparison of Asphalt Concrete Marshall Voids in Mineral Aggregate Vma (%) Of Zycotherm Modified Bitumen and Plain Bitumen At 0% PKS Replacement

	VOIDS IN MINERAL AGGREGATES (%) OBTAINED		
BINDER CONTENT (%)	**PLAIN BITUMEN (0%PKS)**	**ZYCOTHERM MODIFIED BITUMEN (0%PKS)**	**SPECIFICATION**
4.5	16.6	15.32	MINIMUM OF 13%
5.0	17.5	15.86	
5.5	18.6	16.51	
6.0	19.5	16.24	
6.5	19.8	16.70	

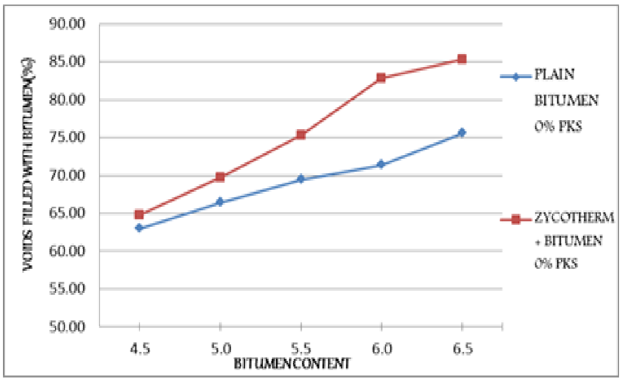


The results show a trend of increase in value of VMA as the binder contents are increased; however the results of VMA show reduction in values as regards the modified bitumen.

Fig. 13: Graph of VMA (%) Variations between the Plain and Zycotherm Modified Bitumen

TABLE-32: Comparison of Asphalt Concrete Marshall Voids Filled With Bitumen (VFB) of Zycotherm Modified Bitumen and Plain Bitumen At 0% PKS Replacement

	VOIDS FILLED WITH BITUMEN (VFB) (%) OBTAINED				
BINDER CONTENT (%)	**PLAIN BITUMEN (0%PKS)**	**ZYCOTHERM MODIFIED BITUMEN (0%PKS)**	**SPECIFICATION**		
4.5	63.0	64.75	LIGHT TRAFFIC (< 10^4 ESALS) 70 - 80	MEDIUM TRAFFIC (10^4 – 10^6 ESALS) 65 - 78	HEAVY TRAFFIC (> 10^6 ESALS) 65- 75
5.0	66.4	69.74			
5.5	69.4	75.29			
6.0	71.3	82.82			
6.5	75.6	85.39			



VFB result variations obtained using both sets of bitumen as volume of voids filled with bitumen in the modified asphalt concrete was higher than that of the plain bitumen.

Fig. 14: Graph of VFB (%) Variation between the Plain and Zycotherm Modified Bitumen

IV. CONCLUSIONS

From the research work results, it shows that PKS can be a viable source of coarse aggregate for partial replacement in asphalt concrete. Partial replacements at 75% and 100% of the 4 – 8mm coarse aggregate portion at optimum binder contents seem to be the best options as both mix result values meet the specifications as regards the conditions for use for light – heavily trafficked roads. However, we cannot rule out the effects of the modifier as the modification of the binder with zycotherm chemical additive seemed to have helped to this effect. This is as test results show that the zycotherm additive also improves asphalt concrete mixtures especially the void characteristics of the mix and is recommended to use in practice.

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