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Performance Evaluation of Stone Mastic Asphalt Containing Palm Kernel and Coconut Shells and their Ashes

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ABSTRACT: *conservation of natural resources and preservation of the environment has led to the concern of many experts in the field of asphalt industry to look at alternative resources to reduce total dependence on petroleum products and conventional aggregates as road construction materials. Agricultural waste recycling has been employed to solve this problem. This study presents an experimental study on the suitability of coconut shell (CCS), palm kernel shell (PKS), coconut shell ash (CSA) and palm kernel ash (PKA) in stone mastic asphalt (SMA) mixtures. CCS and PKS were used as coarse aggregates and CSA and PKA as filler and mixed with conventional aggregates (CA) to produce SMA samples. The results obtained showed that, regardless of the percentage of CCS, PKS, CSA and PKA used to replace CA, the binder content required in the asphalt mixture is high. Though, it was discovered that the mechanical and volumetric properties of the asphalt mixtures were greatly affected by the percentages of CCS and PKS in the mixture, but based on project demand and traffic volume, use of 10% replacement in mixture appears promising and could easily satisfy standard requirements, thus, resulting in durable asphaltic concrete at a reduced cost.*

KEYWORDS: *investigation, palm kernel shells, coconut shell, asphalt mix, stability, cantabro*

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I. INTRODUCTION

The gradual exhaustion of crude oil reserves worldwide and the need for conservation of natural resources and preservation of the environment has led to the concern of many experts in the field of asphalt industry to look at alternative resources to reduce total dependenceon petroleum products and conventional aggregates as road construction materials.There is great demand on existing road network due to increase in traffic loading density in terms of numbers of axles and high pressure resulting from heavy vehicles. The horizontal stresses induced between pavement layers result in crack formation and local settlements thus leading tofailure of the asphalt layers. Pavement distresses, such as: cracking, pot-holes, permanent deformation and surface wear are constantly reported by highway agencies (Tayfur and Ozen, 2008). Over the years, reflection cracking is one of the main distresses that occur frequently in asphalt concrete overlay in which the existing cracking pattern from the old pavement propagates into and through the new overlay. Asphalt binder with additives like crumb rubber, natural rubber and polymers have been used to overcome rutting and travelling in flexible pavements. However, the problem of fatigue cracking is still on the increase. Fatigue cracking occurs due to weakness of bituminous layers in tension. Fiber reinforcement enhances fatigue life by increasing the resistance to cracking and permanent deformation (Mahrez and Karim, 2010).

Asphalt concrete is a composite material commonly used in construction projects such as road surfaces, airports and parking lots. It consists of asphalt or bitumen (used as a binder) and mineral aggregate mixed together lay down in layers and compacted. Mixing of asphalt and aggregate can be accomplished in several ways, one of which is Hot mix asphalt (HMA) this consist of typical gradation that fit into the specifications required in producing the HMA. HMA can be modified with filler, extender, rubber, plastic, rubber-plastic combinations, fibre, antioxidants, hydrocarbon, anti-stripping agents, waste materials etc. Various researchers has shown that fibre and plant shell (either natural or synthetic) can improve the tensile strength and cohesion of HMA admixtures and permit higher asphalt content without significant increase in drain down (Roberts *et al*., 1996). Natural fibre known to have enhanced the properties of HMA includes asbestos, rock wool and jute

(Sharma and Goyal, 2000). While, synthetic or manufactured fibre includes polypropylene, polyester, fibre glass, mineral and cellulose (Mahrez*et al*., 2005). Due to high abrasion resistance, manufactured fibre is more stable and durable admixture as compared to natural fibre. But, since natural fibres also have the potential to be used as admixture in HMA to overcome the inherent deficiencies, there has been sustained interest in utilizing plant shell in HMA mixtures in a view to have alternate road materials which is more economical, sustainable, and eco-friendly (Gassan and Bledzki, 2000). But the use of such shells in SMA mix is scarce.

Currently, synthetic fibers, such as: glass, carbon, polymer, shell (palm kernel and coconut shell) are used in asphalt mix due to their high stiffness and strength properties. Natural fibers such as hemp, coir, jute, oil palm, sisal and flax are a new class of materials which have good potential in bituminous mixes. Depending on their origin, natural fiber can be grouped into bast (jute, banana, flax, hemp, kenaf, mesta), leaf (pineapple, sisal, henequen, screw pine), seed or fruit fiber (coir, cotton, palm kernel, and coconut shell). Different fiber arrangements, such as: short-randomly oriented, long-unidirectional and woven fabrics have been fabricated for natural fiber composites. Therefore, reinforcement of the bituminous mixes is one approach to improve the tensile strength and shell are the most suitable reinforcing material (Yugel, 2007).

Coconut shell is the strongest part covered in coconut fruit located between the coconut flesh and coconut husk. This shell is naturally created to protect the inner part of coconut. While Palm kernel shells (PKS) are derived from the oil palm tree (*elaeisguineensis*), an economically valuable tree, and native to western Africa and widespread throughout the tropics (Omange, 2001). They are used in commercial agriculture in the production of palm oil.

The suitability of palm kernel and coconut shell modified asphalt to improve pavement performance in actual service condition is important (Lee *et al*., 2000). Over the past decades, many studies have look into the effects of natural additives on the properties of conventional bitumen (Jayanti*et al*., 2016). The current use of coconut shell (CS) as an additive or replacement of aggregate in asphalt mixture has drawn considerable attention among researchers (Jeffry *et al*., 2016). However, the use of ash from CS as a replacement for filler in asphalt mix is uncommon. Coconut shell exhibits a high density and can withstand against abrasion and dynamics associated with repeated loading. The shell is similar to hard wood in chemical composition, i.e., high lignin content and low cellulose content. The high lignin content renders the modified asphalt using CS more weather resistant and hence more suitable for application as a construction material.Palm kernel shell is also considered as a waste modifier. By increasing the percentage of Palm kernel shell increases the hardness of bitumen and decreases the value of penetration aging. In addition, the softening point temperature increases in bitumen containing palm kernel shell, thereby improving the aging resistance of bitumen.

In general, bitumen should be modified to reduce temperature susceptibility and improve adhesive and cohesive properties. Hence, this practice will not only give significant impact in recycling agricultural waste materials but also reduce the cost and improve the performance of bitumen.As stated by Fitzegarald, (2000) and Kim, (2009) bitumen modification is one of the approaches to enhance pavement performance when the asphalt concrete produced does not meet the climatic, traffic and pavement structural requirements. Asphalt are modified to achieve; lower stiffness at high temperature associated with construction, high stiffness at high service temperature, lower stiffness and faster relaxation properties at low service temperature, and increase adhesion between the asphalt binder and aggregate in the presence of moisture.The concept of modifying asphalt binders and mixtures is not new. In its earliest stages, asphalt modification involves mixing two or more asphalt binders of different paving grades from different sources. The challenge with this technique is in the possibility that the asphalt cement will be chemically incompatible (Terrel and Epps, 1988).This incompatibility cannot always be effectively predicted, and it can lead to premature asphalt pavement distresses.

II. USE OF ARTIFICIAL MATERIALS IN ASPHALT MIX

Several researchers have used locally available materials to modify or replace conventional materials in asphaltic mixture. Oyedepo and Oluwajana (2014) investigated the properties of bitumen modified with used tyre.Taha*et al.* (2002),evaluated the use of cement bypass dust (CBPD) as filler in asphalt mixtures. Ndoke (2006) examined the performance of palm kernel shells as coarse aggregates in road binder courses with emphasis on strength of the asphalt concrete. Yacob (2016) found that Coconut Shell exhibits high carbon content and can withstand against abrasion and dynamics associated with repeated loading, Xue*et al*. (2008)utilized solid waste incinerator fly ash as a partial replacement of fine aggregate or mineral filler in stone matrix asphalt (SMA) mixes.Pourtahmasb and Karim, (2014) used recycled concrete aggregates to evaluate the performance of stone mastic and hot mix asphalt mixtures.

The use of locally available materials in general and agro-waste in particular is a subject of great interest by many researchers nowadays. This is not only from technological and scientific points of view, but also socially, and economically, in terms of cost and environmental issues. Therefore, it is important that the performance of coconut shell and palm kernel shell and their ashes as mixture in SMA be investigated.Hence the primary aim of this study is to investigate and determine the suitability of coconut and palm kernel shells and their ashes as a partial replacement for coarse aggregates and filler in asphalt mix.

III. MATERIALS AND METHODS

3.1 Materials

Bitumen, granite (coarse) aggregates, stone-dust (fine aggregate), Palm Kernel Shell (PKS), Coconut Shell (CCS), Palm Kernel Shell Ash (PKA) and Coconut Shell Ash (CSA) were obtained for use in this study. The bitumen used which served as binder was sourced from RCC Construction Company in Odeda along Ibadan-Abeokuta expressway, Ogun State, Nigeria. The coarse and fine aggregates were obtained from local suppliers within Ede Osun State Nigeria. Palm Kernel shells were obtained from local palm oil producing industry in Ede,while the coconut shells were collected from local farmer along Owode Ede Osun State, Nigeria. To provide the CCS, freshly discarded Coconut shell with outer skin (exocarp) and coir (mesocarp) removed were collected and cleaned of debris using traditional method (i.e. cutlass and axe). These were sun dried for one week and then crushed and sieved to obtain particles size of 12.5mm (i.e. one retained on sieve 12.5mm). This served as the coarse component. The ash component CSA was obtained by burning the coconut shell for approximately 5min at 450^{0}C to produce coconut shell charcoal which was then grounded into powder form to obtain CSA which served as filler. The same procedure was used to obtain PKS and its ash PKA. Table 1 and 2 present the physical properties of aggregates and that of 80/100 bitumen used in this study for SMA mixtures based on ASTM D3515.

Table 1: Physical Properties of Aggregates

Test	Method	Obtained Values			Standard Requirements
		Conventional Aggregates	CCS	PKS	-
Specific gravity (coarse)	ASTM C127	2.66	1.11	1.60	-
Specific gravity (fine)	ASTM C128	2.63	-	-	-
Water absorption (coarse)	ASTM C127	0.32%	12.14%	2.25%	-
Water absorption (Fine)	ASTM C128	1.01	-	-	-
Aggregate impact value	BS 812: part 3	15.37%	4.26%	7.46%	Below 15%
Aggregate crushing value	BS 812: part 3	30%	38%	36%	Below 30%

Table 2: Physical Properties of 80/100 Binder

Test	Method	Obtained Values	Standard Requirements
Softening point	ASTM D36	50^{0}C	47-49^{0}C
Penetration	ASTM D5	36.3mm	84-95mm
Ductility	ASTM D113	115.3cm	-
Flash point	ASTM D92	280^{0}C	275-302^{0}C
Fire point	ASTM D92	300^{0}C	> 302^{0}C
Specific gravity	ASTM D70	1.1	-

Table 3: Aggregate Content

CA (%)	First Category (%)		Second Category (%)	
	C-CCS	F-PKA	C-PKS	F-CSA
100	-	-	-	-
80	10	10	10	10
60	20	20	20	20
40	30	30	30	30
20	40	40	40	40
0	50	50	50	50

CA = conventional aggregates, C-CCS = coarse coconut shell, F-PKA = filler palm kernel ash, C-PKS = coarse palm kernel shell, F-CSA = filler coconut ash.

3.2 Methods

3.2.1 Sample Preparations:In this study, CCS, PKS, CSA, and PKA were used to replace coarse aggregates and filler in SMA mixtures. 0%, 10%, 20%, 30%, 40% and 50% CCS, PKS, CSA, and PKA were blended with conventional aggregates (CA-coarse aggregates, fine aggregates, and filler) to produce the bituminous samples. These percentages were divided into two categories; in the first category, CCS was used to replace the coarse aggregate and PKA the filler. While in the second, PKS was used to replace coarse aggregate and CSA the filler in the percentages indicated above. The 0% mixture (100% CA mix) was performed as the control mix. SMA aggregate content is shown in Table 3.

Marshall mix design method was used to measure the optimum bituminous content (OBC) of SMA using CA only. 4.6% OBC was used in the mix for preparing samples containing various percentage replacements. To make a better adhesion between aggregates and bitumen during the mix, and remove debris and dust from the CCS and PKS, the materials were thoroughly washed in water then sun dried before being used in the bituminous mix. The required amount of aggregates, fillers and CCS, CSA, PKS, and PKA were weighed and placed in the oven at 200^0C for 2hours, and the required quantity of 80/100 binder was also weighed and heated for a period of 1 hour at 150^0C.

Hot aggregates were mixed with binder at 160 ± 5^0C until all the aggregates were properly coated. The binder and the required amount of filler were then added and mixed thoroughly. All the mixtures were conditioned for 4 hours at 150^0C and then compacted in the Marshall mould with a target of 4% air voids content.

3.3 Marshall Tests

3.3.1 Marshall Stability and Flow Tests: These were accomplished in accordance with ASTM D1559.The Marshall Stability value is the maximum load resistance in Kg or Newtons that the standard test specimen will develop at 60^oC. While the flow value is the total movement or strain in unit of 0.25mm occurring in the specimen between no load and maximum load during the stability test.

3.3.2 Density and Air Voids Tests: the bulk density was determined in accordance with ASTM D2726. Weight in air and water of the samples was taken and the equation below was used to compute the bulk density.

$$G_{MB} = \left(\frac{W_A}{W_{SSD} - W_W}\right) \quad (1)$$

and

$$d = G_{MB} x \rho_W \quad (2)$$

Where: W_A = weight of sample in air (g), W_{SSD} = saturated surface dry weight (g), W_W = weight of sample in water (g), d = bulk density (g/cm^3), G_{MB} = bulk specific gravity of the mix, and ρ_W = density of water (g/cm^3),

Air voids were determined in accordance with ASTM D3203. The air void value of the samples was measured using.

$$VTM = \left[1 - \left(\frac{d}{G_{mm}}\right)\right] x100 \quad (3)$$

Where: VTM = voids in the total mixture, and G_{mm} = theoretical maximum density

3.3.3 Voids in Mineral Aggregates (VMA) and Voids Filled with Asphalt (VFB) Tests: these were determined as follows:

$$VMA = 100\ x \left\{1 - \left[\frac{G_{MB}(1 - b_c)}{G_{SA}}\right]\right\} \quad (4)$$

$$VFB = \left(\frac{VMA - VTM}{VMA}\right) x\ 100 \quad (5)$$

Where: b_c = bituminous content, percent by the weight of mixture, VMA = voids in mineral aggregates, G_{SA} = bulk specific gravity of aggregates, and VFB = voids filled with bitumen.

3.4 Cantabro Abrasion Test: Cantabro Loss is used to determine the abrasion loss of compacted asphalt mix specimens. The test measures the breakdown of compacted specimens utilizing the Los Angeles Abrasion machine. The percent of weight loss (Cantabro Loss) is an indication of durability and relates to the quantity and quality of the asphalt binder. The percentage of weight loss is measured and reported. The mixture is produced in the laboratory in accordance with specification. The compacted specimens are then cooled to room temperature and weighed. These are placed in the Los Angeles testing machine without including the steel balls. The machine is rotated at a speed of 33 revolutions per minute for 300 revolutions. The loose materials broken off the test specimen are discarded and the test specimens are weighed. The Cantabro Loss is computed as follows:

$$CL = \frac{A - B}{A} x100 \quad (4)$$

Where: CL = cantabro loss, A = initial weight of test sample, and B = final weight of test sample.

IV. RESULTS AND DISCUSSION

4.1 Marshall Tests

4.1.1 Stability and Flow Test: The Marshall stability value (MSV) for SMA mixture containing 100% CA was 29.17kN. Figure 1 displays the MSV and flow values of SMA mixtures containing different percentages of C-CCS, F-PKA, C-PKS, and F-CSA content. The results show that as percentage replacement of coarse aggregate and filler increased the MSV decrease and the flow increased. For example, at 10% replacement of coarse aggregate with coconut shell (C-CCS) and 10% replacement of filler with palm kernel ash (F-PKA), the MSV was 18kN andat C-PKS/F-CSA mixit was 20kN. This shows a reduction in MSV as against the 100% CA mixture. The 10% C-CCS/F-PKA and C-PKS/F-CSA exhibit a higher average MSV compared with mixes prepared with 20%, 30%, 40% and 50%. Higher stability indicates stiffer and more resistant mixture. This is in agreement with (Jeffry *et al*., 2016). Also, as the coarse aggregates is replaced with palm kernel shell (C-PKS) and the filler with coconut ash (F-CSA), the stability decreased from 20kN at 10% replacement to 12kN at 50%. This may be due to high water absorption of PKS and CCS. A large amount of filler in the mixture produce lower contact pints between aggregates, hence a lower stability. The result is in agreement with (Abdulwahab*et al*., 2019; Nwaobakata and Agunwamba, 2014).The flow values increased slightly as the percentage replacement increase in both mixtures. Since the same amount of bitumen was used, the flow values in both mixtures are almost similar. The increase in flow values would have been caused by the weak bonds created by both shells and their high water retention ability. The flow increased from 3.76mm at 10% C-CCS/F-PKA mix to 4.5mm at 50% and 3.59mm at 10% C-PKS/F-CSA mix to 4.7mm at 50%, the values are within the range recommended for Nigeria road.

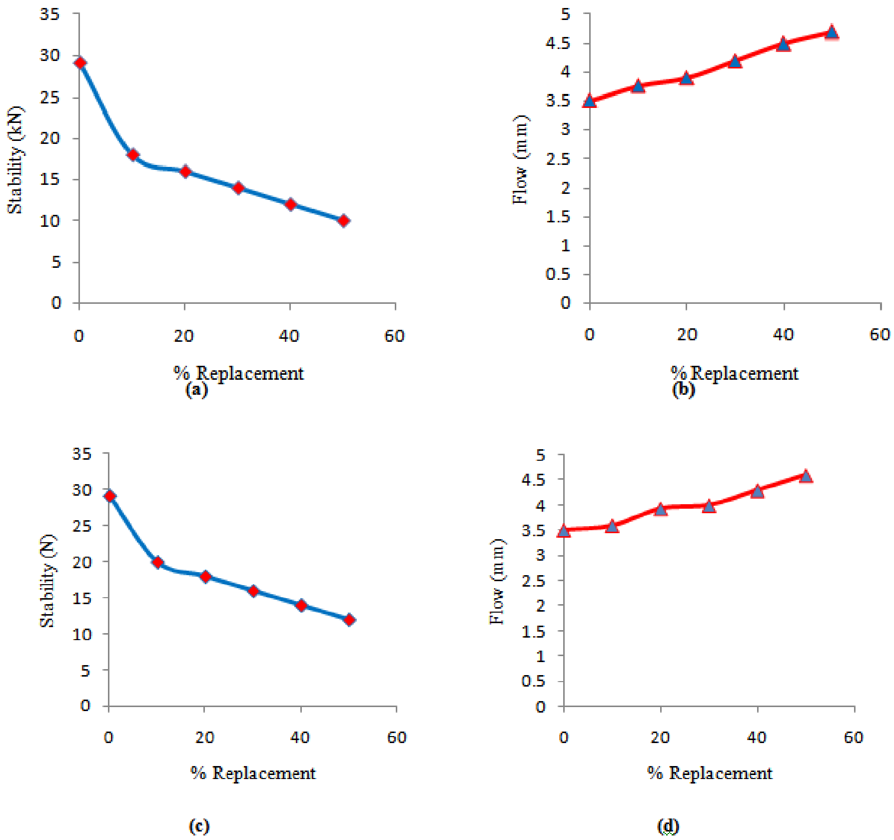


Fig. 1: (a) Stability of C-CCS/F-PKA Specimens. (b) Flow of C-CCS/F-PKA Specimens. (c) Stability of C-PKS/F-CSA Specimens. (d) Flow of C-PKS/F-CSA Specimens.

4.1.2 Density and Air Voids Tests: Figure 2 shows the results of the effects of CCS, CSA, PKS, and PKA on the density and VTM values on the samples. Mixtures containing 100% CA has a measured density of 2.01 and 2.20g/cm^3 for C-CCS/F-PKA and C-PKS/F-CSA mixture respectively. The results revealed that the density values of C-CCS/F-PKA mixture increased as the percentage replacement increase with 50% replacement having a density of 2.42g/cm^3 this is in agreement with results obtained by Jeffry *et al*. (2016) For C-PKS/F-CSA mixture, the density increased from 2.20g/cm^3 at 0% replacement to 2.50g/cm^3 at 3% then decreased to 2.49g/cm^3 at 40% replacement.

In terms of voids in total mix (VTM), SMA samples were produced and compacted with a target of 4% VTM content. Calculated VTM values showed that, regardless of the percentage replacement of coarse aggregates and filler, the air voids values could be easily controlled. SMA samples with 40% and 50% replacement has high VTM values of 8.7 and 9.3% for C-CCS/F-PKA mixture and 6.8 and 7.9% for C-PKS/F-CSA mixture respectively as compared with other percentage replacements.

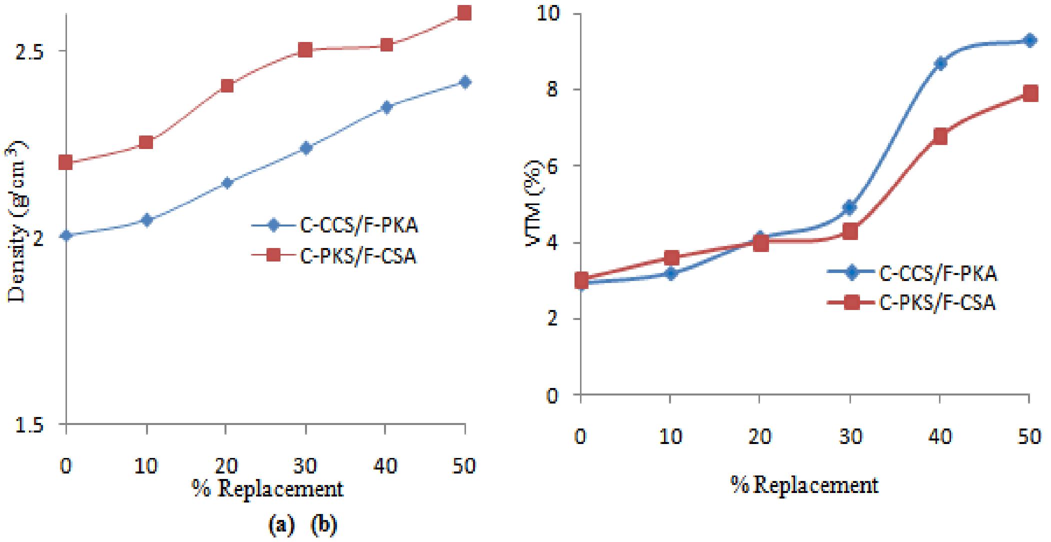
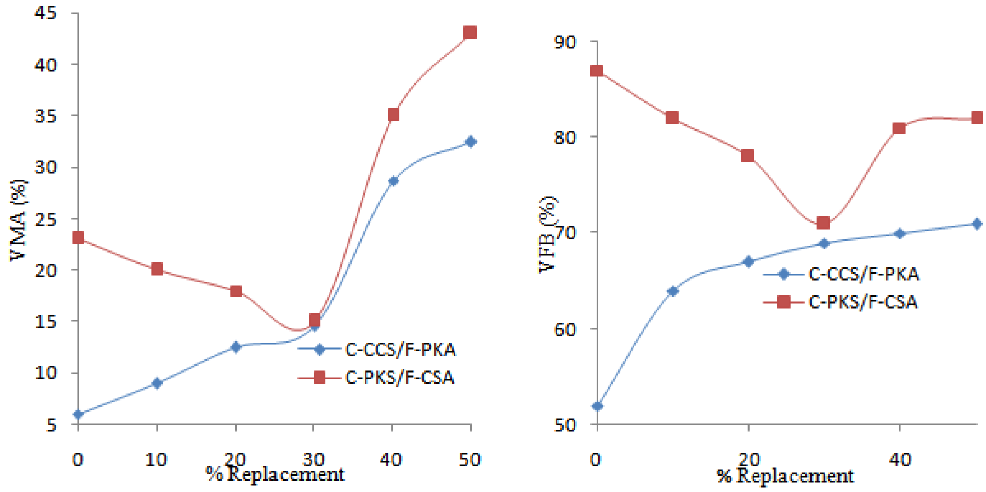


Fig. 2: (a) Density of Samples (b) Air voids of Samples

4.1.3 Voids in Mineral Aggregates (VMA) and Voids Filled with Bitumen (VFB) Tests: mixtures containing 100% CA, has calculated values of VMA and VFA of 52 and 87% for C-CCS/F-PKA and C-PKS/F-CSA respectively. The results showed that, as the percentage replacement increased in the mixtures, the VMA and VFA values also increased (Figure 3). It is believed that the high porosity and absorption of CCS and PKS compared to CA results in higher OBC levels as highly absorptive aggregates required additional binder to fill the permeable voids in the aggregates. Based on Asphalt Institute standard (AI), the minimum acceptable value of VMA is dependent on the nominal maximum aggregates size of the mixtures and desired air void level. The acceptable VFA values for the samples are expected to be from 65% to 78% for highways with low traffic. With the minimum VMA value for SMA been 14%. The results showed that all the samples meet the desired values in terms of VMA and VFA.



(a) (b)

Fig. 3: (a) Voids in Mineral Aggregates of Samples (b) Voids Filled with Bitumen of Samples

4.2 Cantabro Abrasion Test

Mixtures containing C-CCS/F-PKA and C-PKS/F-CSA were tested at different percentage replacement to investigate the effect of CCS and PKS content on durability. The result is presented in Figure 4. As the percentage replacement is increased, the cantabro abrasion loss also increased for C-CCS/F-PKA and C-PKS/F-CSA mixtures. The amount of abrasion loss indicates the inter-aggregate particle cohesion loss in the asphalt mixes tested. The lower the abrasion loss, the less prone the mixtures to disintegration. Asphalt mixes containing both palm kernel and coconut shell generally exhibits lower resistance to abrasion than mixes containing 0%. For instance, at 0%, the abrasion loss of mix is 24.08% while the equivalent value for 10% CS and PKS mix was 43.26% and 44.29% respectively.

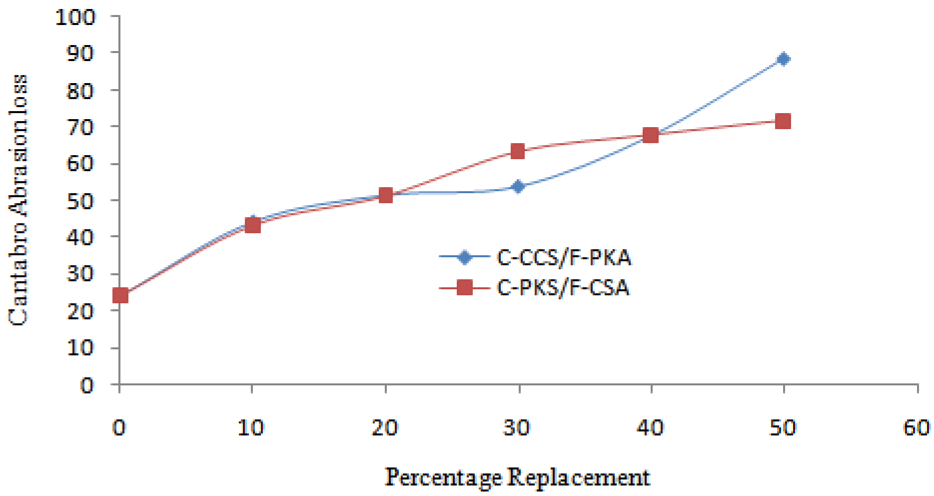


Fig. 4: Cantabro Abrasion Loss of C-CCS/F-PKA and C-PKS/F-CSA Mixtures

IV. CONCLUSION

This study presented the experimental results obtained from the effects of coconut and palm kernel shells and their ashes on the performance of stone mastic asphalt (SMA), the following conclusion are obtained:

i. The maximum stability value obtained is 20N by using palm kernel shells as coarse aggregate and coconut shell ash as filler at OBC of 4.6%, while 18N was obtained when coconut shells were used as coarse aggregate and palm kernel shell ash as filler. This indicates that palm kernel shell has more stability than coconut shell which implies that palm kernel can withstand any sudden shock or impact.

ii. High absorption of CCS and PKS reduces the adhesion between CCS, PKS and binder resulting in their lower impact value compare with the conventional aggregates which make the shell unsuitable for heavy traffic road but can be used for light traffic road. In the course of the experiment, it was found that soaking, proper washing and heating of the CCS and PKS at high temperature before use could increase the performance of SMA mixtures.

iii. Though CCS and PKS in asphalt mixture could affect the mechanical and volumetric properties of the mixtures, use of specific amounts (such as 10%) of CCS and PKS as coarse aggregate and filler in mixtures based on traffic volume can easily satisfy standard requirements which could help in reducing cost of asphaltic concrete and generate economic and environmental benefits.

iv. Based on the Cantabro durability test, it can be inferred that addition of CCS and PKS in higher quantities does not increase resistance to abrasion and the subsequent mix durability. However, 10% replacement for coarse aggregates and filler in mixture appears promising.

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