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Effect of palm kernel shells ash as filler on the mechanical properties of hot mix asphalt

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ABSTRACT

The prime use of asphalt for road and street construction began in the late 1800s, and grew rapidly with the emergent automobile industry. Since that time, asphalt technology has made advancements such that today the equipment, techniques and materials used to build asphalt pavement structures are highly sophisticated. Studies have shown that climate, traffic conditions, characteristics of the asphalt binder and the aggregate are the main factors that can contribute to premature pavement failures. Many countries have recently incorporated filler into their roadway specifications, which had encouraged greater use of the material. The ability of palm kernel shell ash as filler to improve the fatigue and rutting resistance of Hot Mix Asphalt (HMA) as well as moisture sensitivity was investigated. In this study, the mechanistic properties of asphalt concrete mixes modified with PKA as a replacement for limestone dust mineral filler were evaluated. Five replacement rates were used; 1, 2, 3, 4 and 5 percent by weight. Asphalt concrete mixes were prepared at their optimum asphalt content and then tested to evaluate their engineering properties which include moisture damage, permanent deformation and fatigue characteristics. These properties have been evaluated using marshal Stability text and indirect tensile strength. The experimental results, in general, showed that the mixes modified with PKA were found to have improved fatigue and permanent deformation characteristics, also showing lower moisture susceptibility. The use of 3 percent of PKA filler has shown a significant improvement in asphalt concrete behavior and has added to the local knowledge thus possibility of producing more durable mixtures with higher resistance to distress.

Keywords: palm kernel ash, bituminous mixture, fatigue cracking, indirect tensile and moisture susceptibility test.

INTRODUCTION

With the rapid economy growth and continuously increased consumption, a large amount of waste materials is generated [17]. The vast quantities of waste (such as scrap tires, glass, blast furnace slag, and steel slag, plastics, and construction and demolition wastes, agro waste) accumulating in stockpiles and landfills throughout the world are causing disposal problems that are both financially and environmentally expensive. Dealing with the growing problem of disposal of these materials is a concern that requires management and commitment by all parties involved. One solution to a portion of the waste disposal problem is to recycle and use these materials in the construction of highways [2]. The use of waste materials (recovering) in the construction of pavements has benefits in not only decreasing the quantity of waste materials requiring disposal but can provide construction materials with significant savings over new materials. The use of these materials can actually provide value to what was once a costly disposal problem [9]. The overall relevance of asphalt concrete in virtually all highway engineering practice and civil construction works cannot be overemphasized. The growing concern of resource depletion and global pollution has dared many researchers and engineers to seek and develop new materials relying on renewable resources. These include the use of by-products and waste materials in construction. Many of these by-products are used as fillers for the production of acceptable mix design. With the global economic recession coupled with the market inflationary trends, the constituent materials used for these mix design had led to a very high cost of construction. Hence, researchers in material science and engineering are committed to having local materials to partially or fully replace these costly conventional materials. Several successes have been made in these regards and the subject is drawing attention due to its functional benefit of waste reusability and sustainable development. Reduction in construction costs and the ability to produce adequate mix are added advantages [12, 13] assessed the performance of palm kernel shells as a partial replacement for coarse aggregate in asphalt concrete, while [6] investigated the suitability of palm kernel shells as aggregates in light and dense concrete for structural and non-structural purposes. Other similar efforts in the direction of waste management strategies include structural performance of concrete using oil palm shell (OPS) as lightweight aggregate. In addition, other materials explored in partial replacement for concrete 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 has also been investigated [10,14]. Cost of construction in the Niger Delta areas especially the south-south zone is highest. The use of biomaterials in general and agro-waste in particular is a subject of great interest nowadays not only from the technological and scientific points of view, but also socially, and economically, in terms of employment, cost and environmental issues. Nigeria is endowed with a lot of mineral and agro-based resources that could be used in the development of environmental- friendly composite materials such as Eco-pad used in modern vehicle braking systems. As of 2009, Indonesia was the largest producer of palm oil, [4] surpassing Malaysia in 2006, producing more than 20.9 million tonnes. Food Agriculture Organisation (FAO) data showed production increased by over 400% between 1994–2004, to over 8.66 million metric tonnes. In 2008, Malaysia produced 17.7 million tonnes of palm oil on 4,500,000 hectares of land, and was the second largest producer of palm oil, employing more than 570,000 people. Malaysia is the world's second largest exporter of palm oil. As of 2011, Nigeria was the third-largest producer, with more than 2.5 million hectares (6.2×106 acres) under cultivation. Until 1934, Nigeria had been the world's largest producer. From the above statement, large quantities of cracked palm kernel shell (PKS) are therefore generated by the producers. The PKS are obtained after extraction of the palm oil, the nuts are broken and the kernels are removed with the shells mostly left as waste. The PKS are hard stony endocarps that surround the kernel and the shells come in different shapes and sizes [2].These shells are mainly of two types the “Dura” and “Tenera”. The Tenera is a hybrid which has specially been developed to yield high oil content and it has a thin shell thickness compared to Dura type [5, 10]. There are several efforts being made towards the utilization of the PKS. Some of the areas where palm kernel shell are used or are being considered for use include: automobile disk brake pad [5,14], carbon activation for water purification, concrete ingredient in building industry, fuel for heat generation [15], thermal insulator [8,9], etc. The shell is made up of 33% charcoal, 45% pyroligneous liquor and 21% combustible gas as reported [15]. However, some of the detailed biomaterials properties are scarcely found in literatures. The choice of the local product as filler is based on the large quantity of Oil palm grown in Nigeria. These agricultural wastes (waste biomass) impact negatively on the environment because of indiscriminate disposal of such wastes. Hence producing filler from these wastes is an alternative method of waste reduction and reuse. This paper therefore studies the physical properties of palm kernel shell ash as filler with respect to the requirements for hot mix asphalt concrete. The marshal stability test made with varying percentages of palm kernel shell ash (PKA) and indirect tensile strength test were also investigated[16,17].

MATERIALS AND METHODS

The materials used in this research include 40/50 penetration grade bitumen, river sand free from deleterious materials and crushed granite was purchased from a quarry site at mile 3 area of Port Harcourt and periwinkle shells were obtained in sufficient quantities from mile 3 market where they were dumped after the removal of the edible portion. Impurities such as soils and other dirt were removed and the shells were sun dried and oven dry at a temperature of 400c and crushed. And sieved with sieve No 200. Table 1 gives a summary of the result of some of the test performed on the bitumen. Also Table 2 gives some properties of coarse and fine aggregates.

Table 1 physical properties of the bitumen

properties	standard	Bitumen
Specific gravity (g/cm3) at 25^{0}C	ASTM D70	1.05
Ductility (cm) at 25^{0}C	ASTM D113	NA
Penetration (0.1mm), 100g, 5s	ASTM D5	43
Softening point (^{0}C)	ASTM D36	51

Table 2 properties of mineral aggregate

Properties	standard	coarse	fine
Abrasion loss (%) (Los angeles)	ASTM DC 131	30	NA
Specific gravity (g/cm^3)	ASTM C127	2.63	
Specific gravity (g/cm^3)	ASTM C128		2.54

Table 3: Chemical content of palm kernel

Elemental Oxidation	%
SiO2	54.81
Al2O3	11.4
Fe2O3	0.36
CaO	8.79
MgO	6.11
K2O	6.25

2.2 Marshall stability

Marshall Stability and flow test were carried out on compacted specimens at various binder contents according to ASTM D1559. The Marshall test is an empirical test in which cylindrical compacted specimens, 100mm diameter by approximately 63.5mm high are immersed in water at 60^{0}C for 30-40 min and then loaded to failure using curve steel loading plates along a diameter at a constant rate of compression of 51mm/min. The Marshall Stability value in (KN) is the maximum force recorded during compression whilst the flow in (mm) is the deformation recorded at maximum force. The binder content at maximum bulk specific gravity, maximum stability, 4% air void in total mixture, and 80% void in the aggregate mass filled with binder are used in order to determine the optimum binder content.

2.3. Indirect tensile strength test (its)

The indirect tensile strength test (ITS) is performed at loading rate of 51mm/min by using the Marshall apparatus. The (ITS) test involves loading a cylindrical specimen with compressive loads that act parallel and loading diametrical plane. The ITS test is carried out to define the tensile characteristics of asphalt concrete which can be further related to cracking properties of the pavement. To compute the ITS, according to the maximum load carried by a specimen at failure, the following equation is used:

$$ITS=\frac{2P}{\pi hd}$$

Where P_{max} is the maximum applied load (KN), h is thickness of specimen (mm), d is diameter of specimen (mm).

2.4 Resistance to moisture Damage

Moisture susceptibility of asphalt mixture is defined as vulnerability of the mixture to be damaged by water. As moisture is collected within the asphalt mixture, it can damage the bond between the asphalt binder and the aggregates resulting in stripping. The moisture susceptibility of asphalt mixture was evaluated using AASHTO T283 test. The specimens sorted into two subsets were approximately equal. One subset was conditioned by soaking with distilled water for 2days. After soaking they were placed in water bath at 60^{0}C for an hour. Also at the same time the unconditioned specimen were placed water bath at 60^{0}C. After an hour of temperature stabilization, the indirect tensile strength was determined on all specimens. The ratio of the condition indirect tensile strength to unconditioned indirect tensile strength was calculated from the following equation:

$$ITSR=\frac{ITSwet}{ITSdry}$$

Where ITSR is indirect tensile ratio, ITS wet is average indirect tensile strength of wet subset (KPa); ITS dry is average indirect tensile strength of dry subset (KPa). Mixture with tensile strength ratio less than 0.7 or 0.75 i.e (70-75%) are moisture susceptible and moistures with ratios greater than 0.7are relatively resistant to moisture damage

RESULTS AND DISCUSSION

3.1. Marshall Stability

In the Marshall test, the heights of the samples were measured and specimens were immersed in a water bath at 60°C for 35±5 minutes. Specimens were removed from the water bath and quickly placed in the Marshall loading head. The Marshall apparatus deformed the specimen at a constant rate of 50.8 mm per minute. Stability was identified as the maximum load sustained by the sample. Flow was the deformation at maximum load. The stability values were then adjusted with respect to sample height.

Figure 1 shows an initial increase in stability values once the filler content increased in the mixture, but it also decreases with higher filler contents. To increase stability, it seems that there is optimum percentage of filler content. A large amount of filler in the mixture produces lower contact points between aggregates, hence resulting in lower stability.

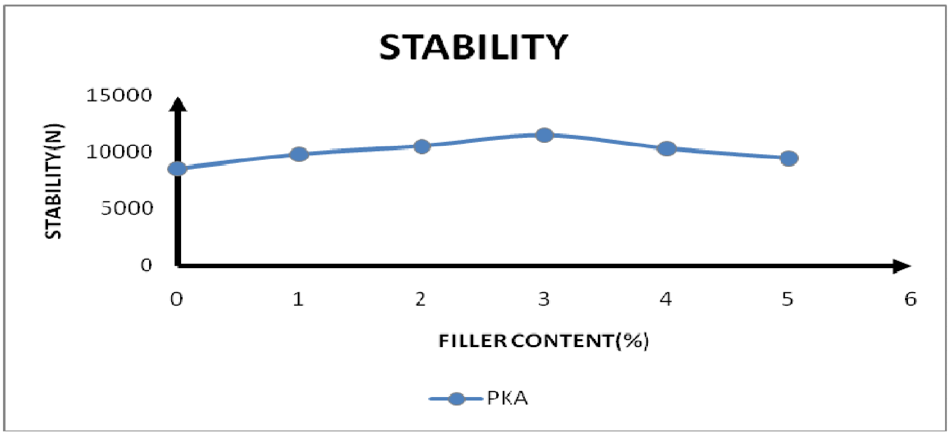

Figure1. Graph of stability vs filler content

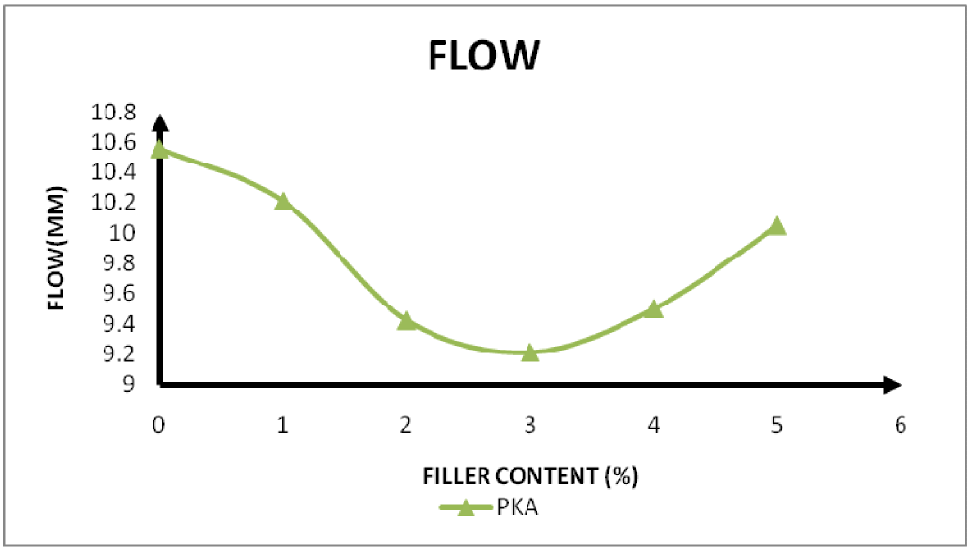

Figure2.Graph of Flow vs. filler content

3.2. Flow Values
Figure 2 shows that an increase in filler content decreases the flow value and as such, when the filler content is higher than 3% (*i.e.* 4% and 5%), the flow values start to increase

3.3 Density
Figure 3 shows an initial increase in density values once the filler content increased in the mixture, but it also decreases with higher filler contents. To increase density, it seems that there is optimum percentage of filler content. A large amount of filler in the mixture produces lower density.

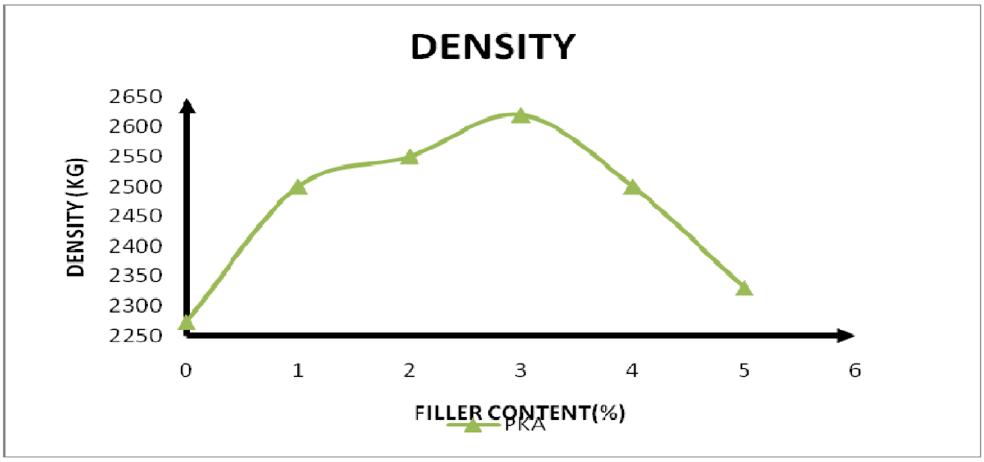

Figure 3: Graph of Density vs. filler content.

3.4. Voids in Mineral Aggregate (VMA)
Figure 4 shows consistent results concerning the effect of filler content on the VMA. Accordingly, an increase in filler content in the mixture followed a decrease in the VMA

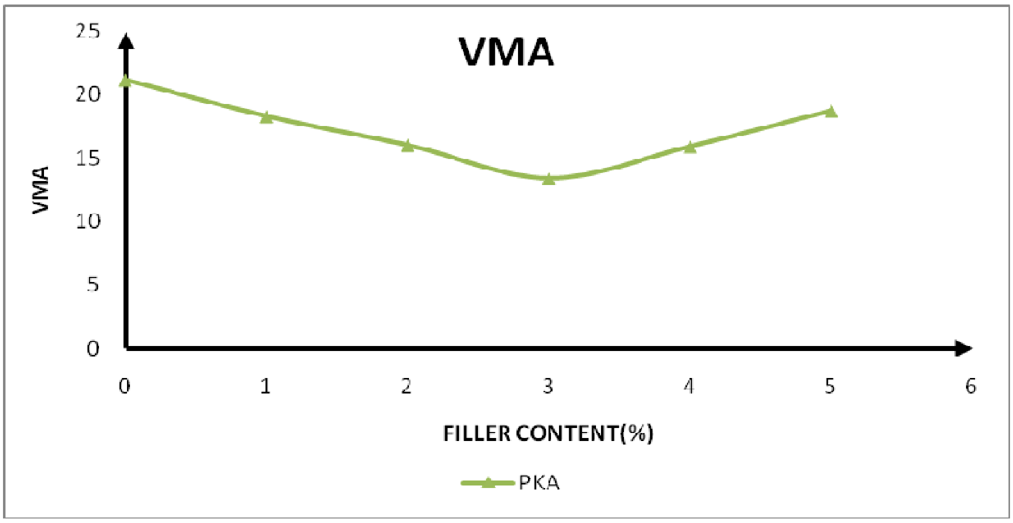

Figure 4: Graph of VMA vs. filler content.

3.5 Air Void
Figure 5 shows that an increase in filler content decreases the air void value linearly.

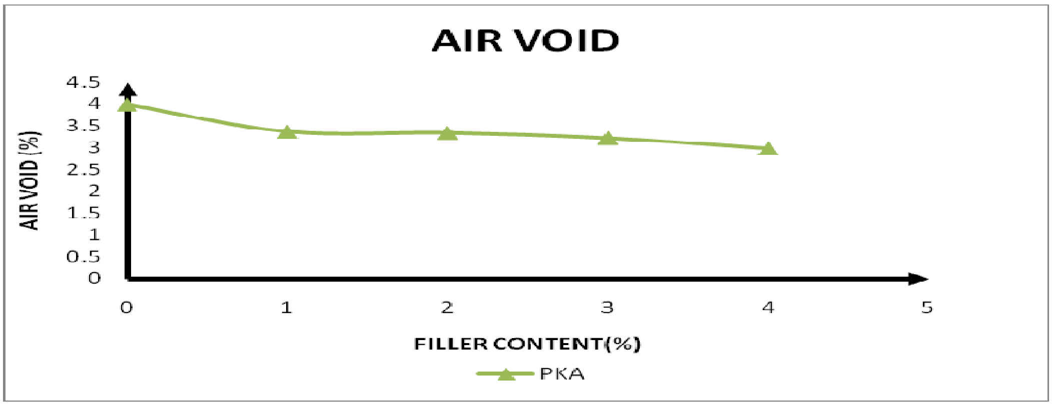

Figure 5: Graph of Air void vs. filler content.

Figure 6 shows consistent results concerning the effect of filler content on the ITSR. Accordingly, an increase in filler content in the mixture followed an increase in the ITSR. Therefore, it can be said that the PSA as filler improved the moisture susceptibility of the mix.

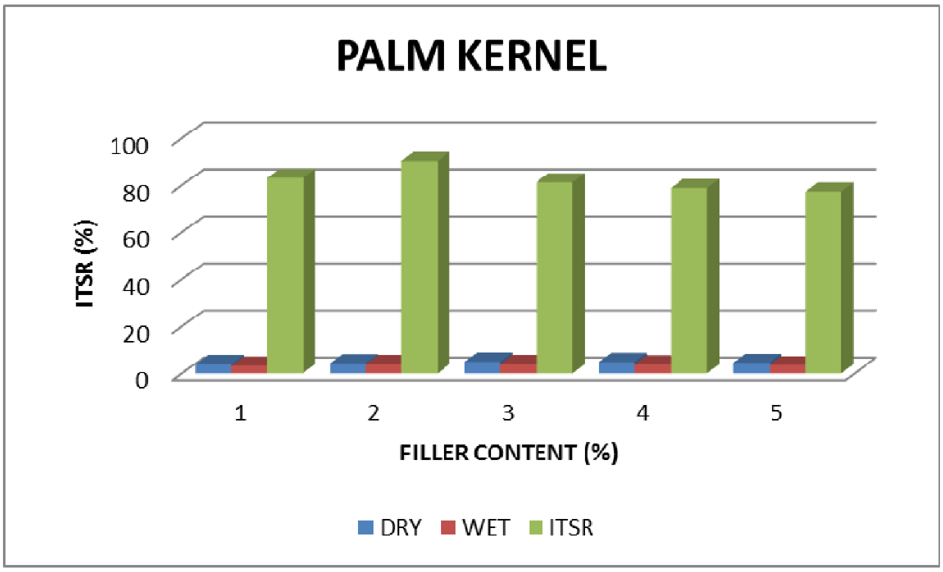

Figure6: Graph of ITSR vs. filler content

3.6 Correlation between Fatigue Life with the stiffness and Deformation Properties of PSA

Figures 7 showed that the correlation factor between the fatigue life and tensile strain was R2 = 0.98. The fatigue life of the specimens showed an inverse correlation with the horizontal strain. In simple words the increase in horizontal strain properties of the specimens is followed by a decrease in fatigue life of the specimens and this is expected and understood.

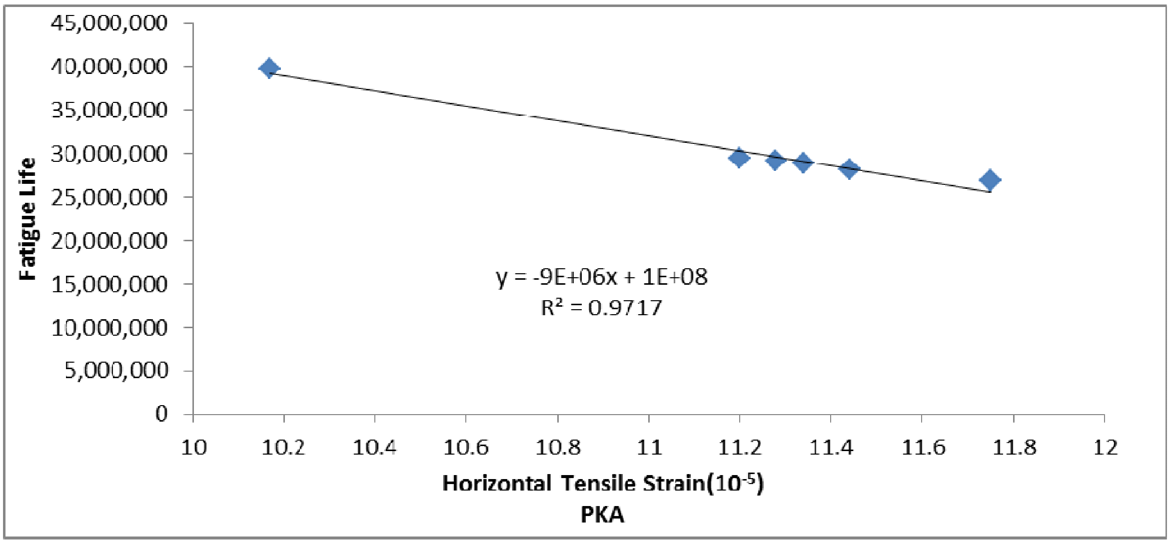

Figure7. Graph of Fatigue vs. horizontal tensile strain

CONCLUSION

The use of palm kernel shell ash as filler revealed consistency of results in the present study. It was observed that the addition of filler positively affects the properties of bituminous mixtures by increasing its stability and voids and decreasing the flow value. As such, it can be said that filler has the potential to improve structural resistance to distress occurring in road pavement due to traffic loads. Further, addition of filler improves fatigue life and permanent deformation of bituminous mixtures by improving mix stiffness. Compared to the control mixture, the filler content of 3% by weight of total mix resulted in highest performance in terms of stiffness, resistance to permanent deformation and fatigue; however, some mechanical properties of the same mix may be compromised when the filler content exceeds 3% level. To achieve these improvements, proper attention must be paid to ensure that the fillers are uniformly dispersed in the mixture. Palm kernel shell ash filler mixtures show significant increases in fatigue life, and moisture resistance, indicating good correlation between fatigue life and permanent deformation. This increase in stiffness is directly related to the addition of filler, and its contents and properties.

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