Behavior of Asphalt Concrete Mixed with Palm Kernel Shells

Madjadoumbaye Jérémie

Department of Civil Engineering, National Advanced School of Public Works
Corresponding author : djerem2002@yahoo.fr

Amine Saïd Njimoluh Baeta

Department of Civil Engineering, National Advanced School of Public Works

aminebaeta@gmail.com

Moussa Sali

University of Douala, Faculty of Industrial Engineering,

s_moussa@fgi-udo.cm

e-mail:454340523@qq.com

ABSTRACT

Nowadays, the road construction sector is facing problems with the high costs of conventional mineral aggregates used in the production of asphalt concrete due to the shortage of these aggregates. Recycling agricultural waste in road construction seems to be a significant solution to this problem. The general objective of this article is to study the behaviour of asphalt concrete mixed with these agricultural wastes, more specifically palm kernel shells. To better understand this subject, a literature review was carried out on the concepts of bituminous concrete and oil palm and its derivatives, particularly Palm Kernel Shells (PKS). The methodology used in this article consists of Marshall tests, bitumen extraction, sieve analysis and absolute density on natural asphalt concrete (BBSG 0/10; combination of 4/6, 6/10 gravel and 0/4 crushed sand) without PKS and on the same BBSG 0/10 with partial replacement of its large aggregates (4/6 and 6/10 gravel) by 10, 30, 50 and 70% of PKS. The main results obtained from these tests, which allow us to characterize the mixtures and determine the contribution of these shells to the mixtures, are the bitumen content, Marshall stability and flow of the mixtures. The results revealed that adding PKS of class 4/10 to the mix increases the bitumen content of these mixtures. According to the Asphalt Institute, the Marshall test results show that palm kernel shells can be used as partial replacement for coarse aggregates up to 70% in low and medium traffic roads, while only blends with 10% and 30% of palm kernel shells can be used for high traffic roads.

KEYWORDS: Palm kernel shells; Mineral aggregates; Bitumen; Marshall test; Traffic.

INTRODUCTION

The sector for the production of asphalt concrete in road construction is by default highly dependent on non-renewable natural materials (gravel) which is becoming scarce due to the overexploitation of these materials. The overexploitation of these materials has cause a sharp increase in its costs, which considerably hinders the development of road infrastructure in the country. This overexploitation also has a negative impact on the environment, particularly with serious consequences on global warming, as it requires the destruction of a significant vegetation cover. In addition, the gradual and permanent disappearance of these materials will in the long term pose educational, sociological and economic problems for future generations. There is therefore a need to use new, less expensive materials that are locally available and can effectively meet the needs of the population.

The agricultural sector has also face problems in disposing agricultural waste, which is local material. A synergistic way to address the above-mentioned challenges facing the road construction and agricultural sector industries is to recycle agricultural waste into road constructions. Moreover, the recycling of these local materials, which are rarely or never used in road construction, has now become a necessary solution to the economic problems of developing countries. This is when new research areas are being explored on asphalt concrete based on agricultural residues capable of solving the economic, technical and environmental problems encountered in the field of road construction. According to the Cameroon Chamber of Commerce, Industry, Mines and Crafts (CCIMA), 70% of the population in Cameroon is primarily engaged in agriculture. It is therefore easy to deduce that the recovery of local materials, particularly those from this sector, seems to be an interesting alternative for solving these problems. With this in mind, consideration has been given to the use of palm kernel shells, which are residues from the exploitation of palm oil (elaeis guinéensis) as a total or partial replacement for mineral aggregates in conventional bituminous concrete. This topic attracts attention because of its functional benefits related to waste reuse and sustainable development, as well as the reduction of construction costs. Several successes have been achieved in this regard by many researchers that PKS could be used as a substitute for conventional aggregates at certain percentages in bituminous concrete (NDOKE P., 2006; Oyedepo O.J. and al, 2015; Mohamed H. and al, 2014; Nwaobakata C. and Agunwamba J. C., 2014). The possibility of using palm kernel shells as subtitutes for coarse aggregates in concrete has also been explored by researchers (Godonou E.F.G., 2014; KATTE R. A., 2015; Okafor F.O., 1988; ACCALOGOUN R. L., 1995; and Osei D.Y. & Jackson E.N., 2012). Also Madjadoumbaye J. and al (2013) decided to study the use of palm kernel shells in laterites in order to improve its bearing capacity. Some authors studied the influence of the treatment of the palm kernel shells on the physical and mechanical properties of light concrete (TRAORE Y. and al, 2014).

In this article, the changes in asphalt concrete due to the contribution of PKS will be presented and also in which type of traffic (intense, medium or light) the different percentages of these PKS can be used as partial replacement for conventional aggregates in asphalt concrete. The various geotechnical tests were carried out at SOL Solution Afrique Centrale.

MATERIALS AND METHODS

Sourcing of materials

The gravel used for this study is of type gneis and comes from Arab Contractors quarry at Eloumden I located in Mbankomo district in the centre region of Cameroon. They are crushed to have two (02) granular classes; 4/6 and 6/10. The 0/4 crushed sand comes from the Ebaka quarry in the Belabo district of eastern Cameroon. The bitumen used here was used as a sample for a control in a road development project in the city of Yaoundé by the laboratory of Sol Solution Afrique Centrale and Labogénie (LABOGENIE, 2018). The bitumen was therefore delivered in sufficient quantity, which ensured that there was sufficient bitumen for this study. The PKS come from a palm grove in the commune of Melong located in the department of Moungo in the Cameroon Coastal region. These

PKS are of type dura. Through a crushing machine and a series of sieves, the classes 4/6 and 6/10 of PKS were produced.

Preparation of the mixture

Specified proportions of each material, i.e. 63% crushed sand of size 0/4, 12% gravel of size 4/6 and 25% gravel of size 6/10 with 6% semi-hard bitumen of class 50/70 of the mixture, were mixed together in a metal tank and heated to a reference temperature of 150 ± 5° C according to the standard NF P 98 250-1. The mixture was compacted with 50 blows both at the top and bottom to obtain cylindrical samples for the Marshall stability and flow tests. Gravel 4/6 and 6/10 were partially replaced by palm kernel shells at 10, 30, 50 and 70% by weight of total coarse aggregate in the mixture. Five samples for each percentage of the shells (even at 0%) were prepared for the various Marshall stability and flow tests and the average of these five results was selected:

- The granulometry assessed by sieve analysis NF P 94-056 ;
- Specific weight using the water pycnometer method NF P 18-554 ;
- The apparent density determined using the NF P 94-053 mould method;
- The hardness of the elements assessed by the Los Angeles and Micro-Deval tests NF P 18-573 and NF P 18-572 respectively;
- The shape of the aggregates determined by the flattening coefficient NF P 18-561 ;
- The cleanliness of the aggregates assessed by the sand equivalent and surface cleanliness tests NF P 18-598 and NF P 18-591 respectively;
- Bitumen penetration test (Penetration at 25° C) NF T 66-004 ;
- Softening point ball and ring method NF T 66-008 ;
- Relative density at 25 ° C NF T 66-007 ;
- Stability and Marshall flow determined through Marshall tests.

RESULTS AND INTERPRETATIONS

The following results are the average values obtained from the various tests carried out on aggregates, palm kernel shells, bitumen and bituminous mixtures.

Properties of mineral aggregates and palm kernel shell aggregates

Table 1: Physical properties of palmist aggregates and shells

Laboratory tests	Crushed sand 0/4	Gravel 4/6,3	Gravel 6,3/10	Palm kernel shells	Specific-ations
Water content w (%)	0.512	0.280	0.279	4.101	/
Flattening coefficient (%)	2.698	7.807	9.265	37.067	< 20
Bulk density	2.737	2.872	2.882	1.440	/
(g/cm^3)	1.542	1.505	1.498	0.570	
Apparent density (g/cm^3)	/	28.4	26.3	2.8	< 35
Los Angeles (%)	/	20.3	17.9	11.3	≤ 25
Micro-Deval (%)	96	/	/	/	> 40
Sand equivalent (%)	/	0.7	0.8	/	< 1

The physical and mechanical properties of aggregates and PKS are shown in Table 1 while their sieve analysis results are shown in Figure 1. Table 1 shows that the value of the specific weights and bulk density of the aggregates (gravel and sand) places them in the heavy aggregate category. Their specific weight is in line with those generally used for asphalt concrete (2.62 to 3.0). The value of the sand equivalent of sand 0/4 shows that the sand used is very clean (which means that the sand contains almost no organic matter and clay). Table 1 also shows that the specific weight of PKS is lower than that of aggregates generally used (between 2.62 and 3.0) in asphalt concrete. This shows that aggregates are heavier than the shells. However, the dry bulk density of 0.51 of the shells puts them in the same category as lightweight aggregates such as Pumice, Scoria and Vermiculate. The value of the Los Angeles and micro deval coefficients shows that shells are hard materials that are resistant fragmentation and wear.

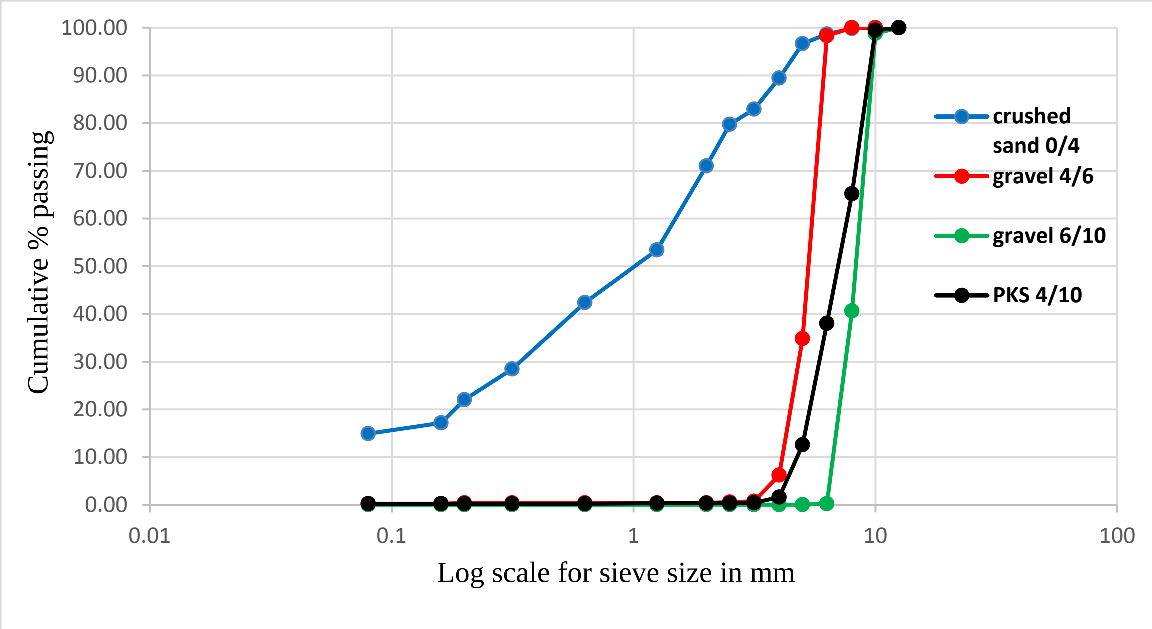

Figure 1: Aggregate and shell grain size curve for palm nut aggregates and shells

Figure 1 shows that the granulometric analysis of hulls is represented by a curve similar to those of 4/6 and 6/10 gravels, which shows that hulls can be used as a replacement for gravels (or coarse aggregates) in the mixture.

Properties of Bitumen

The hydrocarbon binder used in this study is a pure semi-hard bitumen of class 50/70 complying with NF T 65-000 and NF T 65-001 standards. The properties of this bitumen were obtained in the laboratory and listed in Table 2.

Table 2: Properties of the bitumen used

Characteristics	Results obtained	Specifications
Penetration à 25° C, 100 g, 5s 1/10 mm	0.512	0.280
Softening point ball and ring (° C)	2.698	7.807
Relative density at 25°C on the pycnometer (g/cm^3)	2.737	2.872

Properties of bituminous mixtures

Table 3 provides a summary of the characteristics of the different bituminous mixtures at different percentages of palm kernel shells.

Table 3: Mixture characteristics at 0, 10, 30, 50 and 70% of PKS

Characteristics	% des Palm Kernel Shells					Specifications
	0	10	30	50	70	
Bitumen content (%)	5.60	6.50	6.58	6.65	6.87	5 – 8
Specific surface area Σ (m^2/kg)	15.08	15.08	15.09	15.10	15.23	/
Finness modulus k	3.25	3.78	3.82	3.86	3.98	3 – 4
Geometric density (g/cm^3)	2.256	2.188	2.058	1.958	1.875	/
Apparent density (MVa) (g/cm^3)	2.303	2.223	2.083	1.971	1.881	/
Real Density (MVR) (g/cm^3)	2.425	2.374	2.290	2.241	2.207	/
Compactness (%)	94.97	93.64	90.96	87.95	85.23	> 96
% vides	5.03	6.36	9.04	12.05	14.77	5 – 9
Marshall stability à 60° C (kg)	986.1	917.8	816.1	704.1	613.2	> 815
Marshall flow (1/10 mm)	3.29	3.62	3.98	4.37	4.79	< 4

Table 3 shows that the shells have a synthetic character in the direction of the bitumen, which means that they have a low absorption rate of the bitumen. Increases were noted in the values of the k richness modules (due to the increase in bitumen content), however the blends at 10 and 30% remained below the specified range of maximum 4. The results in Table 3 also show that, on average, when coarse aggregates are reduced and hulls added, Marshall stability decreases while creep increases. The increase in creep is caused by a weak binding force created by the hulls in the mixture. Although increases in creep values were observed, the 10 and 30% mixes nevertheless remained below the specified range of maximum 4mm. The stability values obtained with 10, 30, 50, and 70% shells as partial replacement for coarse aggregates are respectively 917.8 kg, 816.1 kg, 704.1 kg and 613.2 kg. The Marshall design criteria provided by the Asphalt Institute require minimum values for the different traffic classes as follows:

- 340 kg for light traffic.
- 544 kg for medium traffic.
- 815 kg for heavy or intense traffic

It is clear that all Marshall stability values obtained from the mixes are higher than the minimum value for light and medium traffic, and therefore all mixes with partial replacement of large aggregates up to 70% can be used for light and medium traffic pavements. It can also be seen that mixtures with 50 and 70% hulls have a stability higher than that specified for average traffic but lower than that specified for heavy or heavy traffic, which makes the replacement of coarse aggregates by 50 and 70% hulls unusable for heavy traffic pavements. And finally, it is shown that the stability values for blends with 10 and 30% hulls are higher than the minimum value specified for heavy traffic and therefore, the replacement of the coarse aggregates with PKS at 10 and 30% can be used for any type of traffic. Figure 2 shows the variation between the stability of the blends as a function of the percentage of PKS used, and also indicates the traffic classes in which these blends are located.

Table 4: Percentage of palm kernel shells with respect to traffic

% palm kernel shells	Traffic		
	Light T1 et T2	Medium T3 et T4	Heavy T5
10	Good	Good	Good
30	Good	Good	Good
50	Good	Good	Bad
70	Good	Good	Bad

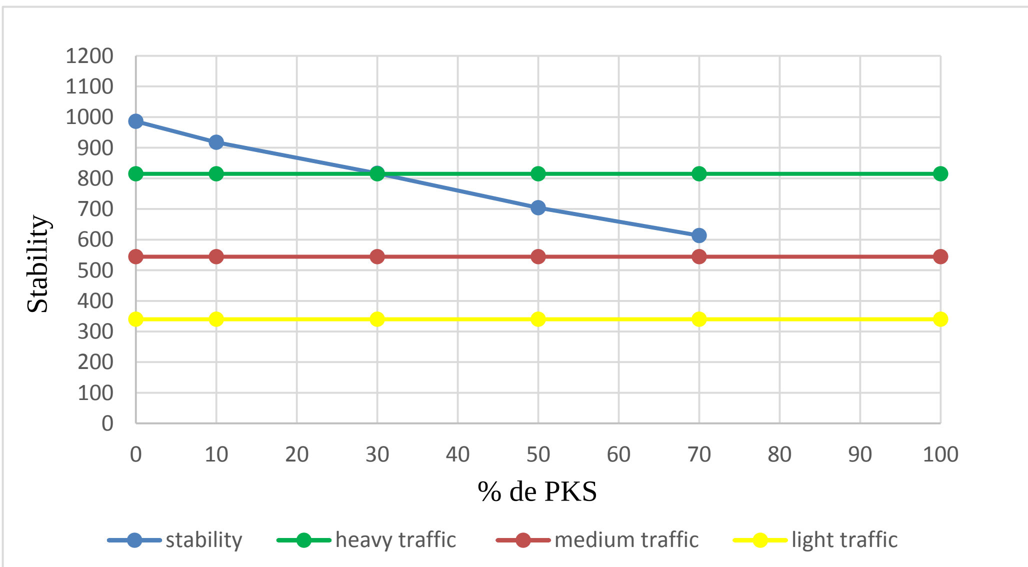

Figure 2: Marshall stability curve of PKS mixtures with minimum values for heavy, light and medium traffic.

CONCLUSIONS

From the results obtained, the following conclusions were drawn:

•The bitumen content of shell-based bituminous mixtures increases as shells are added, which means that the amount of bitumen can be reduced from the start to the desired bitumen content.

•Palm kernel shells can be used as a partial replacement for coarse aggregates up to 10% and 30% for heavy traffic roads (major city roads), and 50% and 70% for medium traffic roads (low-traffic roads such as some rural communities and large city districts).

This study also highlights the advantages of using shells as a partial substitute for aggregates in asphalt concrete for the economy and urban development of Cameroon as follows:

•The cost of road construction and maintenance can be significantly reduced through the use of these hulls, which have a low economic value. This contributed greatly to the increase in roads in the country and eventually to its urban development.

•The economic power of rural people will be strengthened if they are encouraged to plant palm trees from which these shells could be obtained.

•The creation of palm trees will greatly contribute to the production of oil and its derivatives, particularly cockles, which will increase the gross domestic product (GDP) due to the export of palm oil from Cameroon while increasing the number of roads. The unemployment rate can also be reduced through the creation of these palm trees.

•Finally, the environmental risks associated with a total dependence on conventional materials can be minimized with the use of shells.

However, one of the main limitations of bituminous concretes in shells is their low compactness rate, which is due to a high percentage of voids in the mixture. For the improvement of this work, additional studies will be necessary in order to better understand these blends. Some of these studies are as follows:

•Behaviour of BB at 15%, 20%, 25%, 25%, 35%, 40%, 45% palm kernel shells.

•Find a new shell grain size for reducing voids in the bituminous mix.

•Improving the compactness of bituminous concrete in hulls with fillers or other types of additives such as cement and lime.

•The influence of hull treatment (to reduce its high water absorption rate) on the physical and mechanical properties of asphalt concrete.

•Study of the durability of bituminous concretes in palm kernel shells.

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