Full Paper

SOME PHYSICAL AND MECHANICAL PROPERTIES OF PALM NUT AND COCONUT SHELLS RELATED TO SIZE REDUCTION PROCESSES

O. Kayode
Department of Mechanical Engineering, Osun State University, Osogbo.

O.A. Koya
Department of Mechanical Engineering, Obafemi Awolowo University, Ile-Ife. afemikoya@yahoo.com

ABSTRACT

The study evaluated the physical and mechanical properties of palm kernel shell (PKS) and coconut shell (CNS) relevant to their size reduction processes. The shells, obtained from local processing mills, were washed, sun-dried and sorted to remove kernels, nuts and other extraneous materials. Experiments were then conducted to determine the thickness, density, moisture content, and hardness of the shells. Fracture resistances were characterised by the average compressive load, stiffness and toughness at bio-yield point of specially prepared section of the shells, under quasi-static compression loading. The densities of the dried PKS at 7.12% and the CNS at 6.47% (wb) moisture contents were 1291.20 and 1247.40 kg/m^3, respectively. The corresponding Brinnel Hardness Numbers were 58.40 ± 1.91 and 56.33 ± 4.33. The findings further showed that both shell types exhibited higher resistance with compression along the longitudinal axes than the transverse axes. With compressions along the longitudinal axes, the fracture force were 1.41 ± 0.11 and 3.62 ± 0.09 kN; bio-stiffness; 934.70 ± 67.03 kN/m and 1980.74 ± 8.92 kN/m; and toughness, 2.17 ± 0.16 and 6.51 ± 0.15 KN mm for the PKS and CNS, respectively.

Keywords: *Palm kernel shell, coconut shell, hammermill, crushing strength, bio-stiffness, toughness*

1. INTRODUCTION

Palm Kernel Shell (PKS) and Coconut Shell (CNS) are finding applications as raw materials in the development of asbestos-free friction linings, and as fuels in fluidized bed combustors (Fono, 2009; Adio and Asere, 2009). However, the shells must be ground to specific particle size range with negligible quantity of fines before they can be employed in these applications. The particle size required in fluidized bed combustors ranges from 1.4 mm to a maximum of 50 mm (Patumsawad, 2001; Eswaraiah et al., 2008; Adio and Asere, 2009; La Nauze, 1987). The reported particle sizes for PKS as used in friction linings was between 125 μm and 0.1mm (Fono, 2009; Ibadode and Dagwa, 2008).

The two most common industrial grinders are the hammer mill and the roller mill, but the hammer mill is simpler in design, more versatile, and finds applications in grinding a wider variety of materials, at relatively lower maintenance cost (Koch, 2002). The major basic machine parameters, namely, the screen size, feed rate and shaft speed, are readily adjusted to give the desired product size based on the intrinsic physical and mechanical properties of the material (Earle, 1983). Therefore, researchers have measured energy requirements directly, in hammer mill comminution of grasses, straw, corn stover, and coals, to deduce optimum machine operating parameters for desirable product size distribution (Bitra *et al*., 2009; Eswaraiah *et al*., 2008; Gotsis *et al*., 1985). However, no results have been published on size reduction of PKS and CNS, which belong to a class of material different from the natural minerals and fibrous agricultural residues, in which extensive works have been reported. It is therefore worthwhile to investigate the fracture behaviour of these hard nutshells in view of the increase interest to modify the shells for more recent engineering applications.

Studies have also shown that the product particle size in the fracture of brittle materials strongly depends on the collision energy and the impact velocity (Potapov and Campell, 1994) whilst, the fracture force is a function of the material linear dimension, hardness and toughness. Fracture force is defined as the minimum load to initiate microscopic failure of the material. Studies have been undertaken on the fracture resistances of agricultural materials, such as, sections of Macadamia nutshell, whole palm nut and Dika nut (Ogunsina et al., 2008; Koya and Feborode, 2005;Wang and Mai, 1994). Therefore, the main objective of this work was to determine the physical and mechanical properties required in estimating the minimum fracture energy in the size reduction of PKS and CNS.

2. MATERIALS AND METHODS

Palm kernel shell samples were obtained from a palm oil processing mill in the Teaching and Research Farm of Obafemi Awolowo University in Ile-Ife; while, CNS samples were obtained from Badagry, Lagos State, where large clusters of copra processing mills are located. The shells were washed and dried under ambient conditions, until they were sufficiently dried as recommended by previous researchers who had used the nutshells for some engineering applications (Fono, 2009; Adio and Asere, 2009). Whole nuts were also carefully sectioned Fig. 1) and subjected to the same drying conditions as the raw broken shells, to prepare samples for the compression tests

2.1. Physical Properties

The physical properties of the materials were characterised by the thickness, density, and hardness of the nutshells. The moisture content of the nutshells at the time of experiment was determined following Standard S358.2 (ASAE, 2001). A quantity of the sample was dried in an electric oven, with thermostatic control, for up to six hours while maintaining the oven temperature between 105 and 110 ^{0}C. The weight of the sample was noted at regular intervals until a constant weight was observed in three consecutive readings. The moisture content was then calculated from Equation 1.

$$MC\% = \frac{M_W - M_D}{M_W} \times 100 \quad (1)$$

where, MC% = percentage moisture content of the sample (wet basis);
M_w = mass of wet sample in kg;
M_D = mass of dried sample in kg.

Three replicates of moisture analysis were performed for each of the feedstock.

The density of each of the feed stocks was determined as mass/volume ratio of the sample. The sample was weighed on an electronic top balance (PL 203, Mettler Toledo, Taiwan) with accuracy of ± 0.01 g, while its volume was determined by water displacement method, using a measuring cylinder with accuracy of ± 0.05 ml.

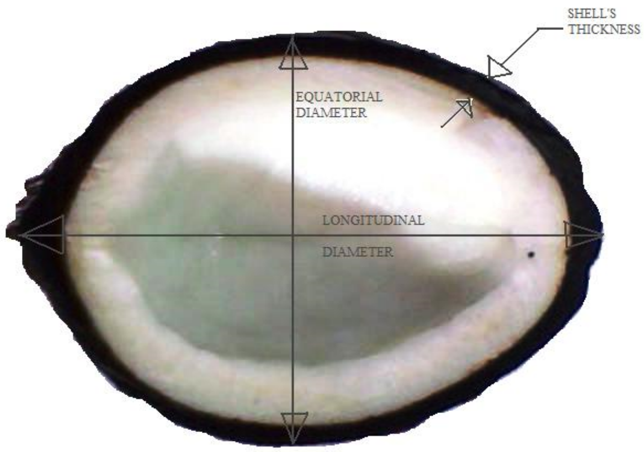

Fig. 1. Sectioned coconut fruit depicting the longitudinal and equatorial diameters as well as the shell's thickness.

Brinell hardness test was carried out on the PKS and CNS samples using a Tensometer (Type W, Monsanto, UK). A hardened steel ball (10 mm diameter) was pressed into the test specimen, under a 5 kN load. The diameter of the indentation made by the ball on the shell fragment was then measured with the aid of a micrometre microscope (MA523, Meiji Techno, Japan). Two diameters, at right angle to each other were measured for each indentation and the average was used in the computation of the Brinell hardness number (Equation 2).

$$BHN = \frac{W}{\left(\frac{\pi D}{2}\right)\left(D-\sqrt{D^2-d^2}\right)} \quad \ldots \quad \ldots \quad \ldots \quad (2)$$

where BHN = Brinell Hardness Number,
W = applied load in kN.
D = diameter of the spherical ball indenter in mm;
d = mean diameter of the resulting indentation in mm.

2.2. Mechanical Properties

The mechanical properties of the shells were described by the fracture force; bio-stiffness and toughness at bio-yield points on the force-deformation curves. The test specimens for CNS were prepared by cutting whole coconut and palm nut transversely, along the equator, to produce an upper (pointed) hemispherical section and a lower (rounded) hemispherical section. The third specimen for CNS was prepared by cutting a whole coconut shell longitudinally into two equal halves (Fig. 1). The copra or kernel was carefully removed from each specimen, and the shells were sufficiently dried under the ambient temperature to avoid possible thermal stress crack in oven drying. The average equatorial and longitudinal diameters and thickness of the nutshells were measured using a digital vernier caliper (CP9806-TF, Carrera Precision, USA).

Each sample was subjected to quasi-static compression between two rigid parallel plates (Fig. 2), using an Instron Universal Testing Machine (INSTRON 3369, USA) integrated with a computer for graphical display of the experimental results. The loading rate for each specimen was maintained at a constant rate of 5 mm/min as recommended by ASAE Standard S368.3 (ASAE, 1998). The resulting load-deformation curves were then analysed to determine the fracture force, bio-stiffness, and the toughness of the samples.

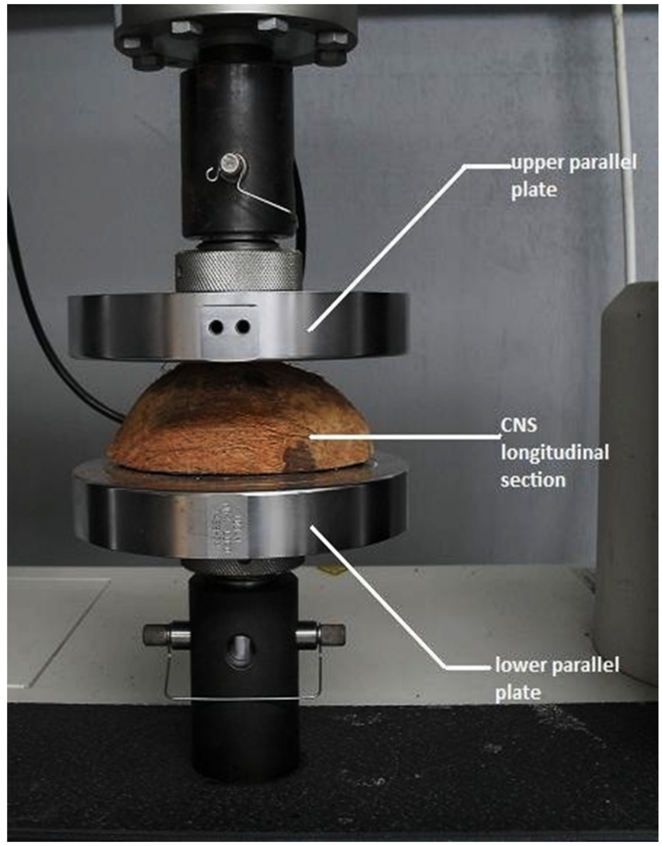

Fig. 2. Orientation of longitudinal section of coconut shell sample under compression test

The upper limit of the apparent linear-elastic portion of the curve represents the on-set of nutshell fracture and taken as the fracture force (Mohsenin, 1986; Oloso and Clarke, 1993). The bio-stiffness for each shell was defined as the ratio of load to deformation for the elastic portion of the load-deformation curve. Toughness of a brittle material under external load is defined as the energy absorbed per unit volume of material to cause fracture; where, energy absorbed was determined from the integration of the load-deformation, from the origin to the bio-yield point (Ogunsina *et al.*, 2008).

3. RESULTS AND DISCUSSION

3.1. Physical Characteristics

The moisture contents of PKS and CNS samples at the time of the experiment were 7.12 and 6.47% (w.b.), respectively. It is well recognised that high moisture content may lead to the clogging of the machine parts with corresponding increase in energy consumption (Skilling, 2001). On the other hand, dry feedstock improves friability, but leads to excessive generation of fines and dust (Earle, 1983). However, Kayode (2011) reported no clogging of machine moving parts and a minimal generation of dust in milling PKS and CNS respectively at 7.12 and 6.47 % (w.b.)

The density of the PKS was 1291.2 kg/m^3; while, that of the CNS was 1247.4 kg/m^3, The Brinell hardness numbers for PKS and CNS were 58.42 ± 1.91 and 56.33 ± 3.33, respectively. The similarity in the degree of hardness and the densities of the two nutshells may be due to the uniqueness of their origin from the palm family. The Summary of the physical and mechanical characteristics of the shells is shown in Table 1.

Table 1: Summary of Physical and Mechanical Properties of PKS and CNS used in the Experiment

Properties	Replicates	PKS[a]	CNS[a]
Moisture content (% wet basis)	3	7.12 ± 0.16 %	6.47 ± 0.51%
Shell thickness (mm)			
At the edge of cut	6	3.77 ± 0.49	5.08 ± 0.35
Axial dimensions of whole nut (mm)			
Longitudinal diameter	6	26.15 ± 0.50	120.30 ± 1.98
Equatorial diameter	6	18.00 ± 0.57	82.40 ± 1.68
Crushing strength (kN)			
Upper hemispherical section	2	1.41 ± 0.11	3.62 ± 0.09
Lower hemispherical section	2	*	2.62 ± 0.04
Longitudinal section	2	1.34 ± 0.02	2.51 ± 0.12
Bio-stiffness (kN/m)			
Upper hemispherical section	2	934.70 ± 67.03	1980.74 ± 8.12
Lower hemispherical section	2	*	1540.59 ± 21.62
Longitudinal section	2	830.36 ± 4.93	1255.00 ± 60.81
Toughness (kNmm)			
Upper hemispherical section	2	2.17 ± 0.16	6.51 ± 0.15
Lower hemispherical section	2	*	4.69 ± 0.03
Longitudinal section	2	2.14 ± 0.04	5.02 0.24

3.2. Compressive Strength Properties

The force-deformation curves at a constant loading rate of 5 mm/minute for the two nutshells are shown in Fig. 3. Apart from an initial short non-linear deformation observed for CNS samples, which may be attributed to the settling of the specimens between the parallel plates, each curve consists of two segments. The first segment reflects material deformation up to the bio-yield point. This segment exhibits a linear relationship between load and deflection, representing the primary resistance of the shell, preceding the initiation of shell fracture at the bio-yield (Mohsenin, 1986).

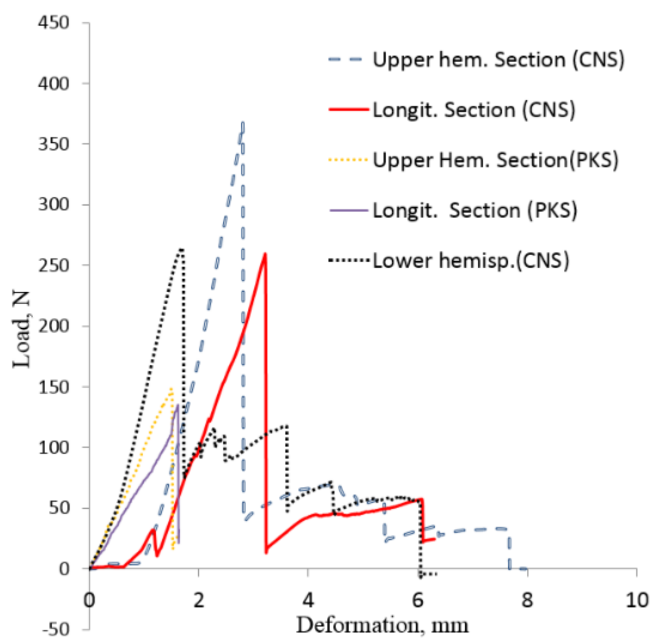

Fig. 3. Load-deformation curves for sections of coconut shells and palm kernel shells compressed between two parallel plates at 5 mm/min loading rate

The fracture load for CNS varies from 2.51 to 3.62 kN, while that of PKS varies from 1.34 to 1.41 kN. These results are comparable to the range obtained for some hard nut shells, such as, macadamia nut (0.6 – 1.8 kN) and Dika nut (2.06 – 3.67 kN) (Wang *et al*., 1995; Ogunsina *et al*., 2008). The observed bio-yield point was generally higher for CNS samples than for PKS samples. It thus appears that the fracture force is dependent on the size of the nutshell, as reported for whole palm nut (Koya and Faborode, 2005) and whole Dika nut (Ogunsina *et al*., 2008). Furthermore, the upper hemispherical (pointed) sections gave greater fracture strength than the basal ends and the longitudinal sections. This observation is reasonable on account of the spongy structure of the nut at this end, which enhances its resistance to fracture. The fracture force of the upper hemispherical end, therefore, represents the load to adequately crush the nutshell; while the margin above the lower fracture force for the other sections of the nutshell will, in theory, result in grinding the nutshells into fines.The second segment of the curve covered the portion from the bio-yield point to the point where the shell experienced catastrophic (brittle) failure. The secondary deformation of the CNS is possibly a crushing process and a re-arrangement of the particle under load application; while the PKS, because of its small size, splitters and dislodge from the machine, abruptly terminating its compression.

The summary of the values of mechanical properties thus obtained were as presented in Table 1.

The stiffness moduli for PKS are generally lower than that of much relatively bigger, but identically thick CNS. The stiffness moduli of the nutshells are higher for upper hemispherical sections than for any other section, and generally higher in CNS than PKS. Resistance to fracture is directly related to stiffness modulus, so that, increase in resistance to fracture increases the comminution energy (Earle, 1983). This implies that more energy will be consumed in the comminution of CNS than for PKS. Similar trend was observed in the toughness values (see Table 1). As expected, estimated toughness of CNS is higher than for PKS, with an average value of 6.51 ± 0.15 kNmm for compression of the upper hemispherical section. This further confirms relatively greater comminution energy for CNS as compared to PKS. In practice, the impact energy applied over a short interval need to be greater than the compressive energy to cause the same degree of material fracture, since impact occurs at higher deformation rate. Consequently, the stiffness moduli and the toughness of the nutshell would be useful in determining the setting of impact grinder for desirable product quality with minimal fines generation.

4. CONCLUSIONS

Based on the need to modify palm kernel and coconut shells for some engineering applications, the study evaluated some physical characteristics and fracture resistance, relevant in estimating energy requirements in grinding the nutshells. Significant observations in the study are summarised as follow:

i. The PKS and the CNS, respectively at 7.12 and 6.47% moisture content (wet bases) and close shell thickness, exhibited identical physical properties; although, CNS is relatively larger in physical dimensions than PKS.
ii. The fracture resistance of CNS is higher than for PKS, with maximum average values of 3.62 kN in fracture force; 1980.74 kN/m in bio-stiffness; and 6.51 kNmm for the upper hemispherical section of the nutshell.
iii. With the estimated toughness of 6.51 ± 0.15 kNmm for CNS, higher than for PKS (2.17 ± 0.16 kNmm) the study shows the requirement of higher comminution energy for CNS.

ACKNOWLEDGEMENT

This study was partly funded by the National Mathematical Centre and the Raw Materials Research and Development Council, both in Abuja, Nigeria.

REFERENCES

Adio, S. A. and Asere, A. A.: 'A study of thermal and emission characteristics of a coconut shells in a fluidized bed combustors'. Procedings of 22nd Annual General Meeting and International Conference of the Nigeria Institute of Mechanical Engineers, 215-219, 2009

ASAE : 'Compression Test of Food Materials of Convex Shape' (ASAE S368.3 MAR95) American Society of Agricultural Engineers, 1998

ASAE: 'Moisture measurement for forages'. St. Joseph,MI: *American Society of Agricultural Engineers*, Standards S358.2 , 47th ed. ,579. 2001

Bitra, V.S.P., Womac, A.R., Chevanan, N., Miu, P.I., Igathinathane, C., Sokhansanj, S. and

Smith, D.R.: 'Direct mechanical energy measures of hammer mill comminution of switch grass, wheat straw and corn stover and analysis of their particle size distributions'. *PowderTechnology*, 100: 6578 – 6585. 2009

Earle, R.L.: Unit Operations in Food Processing: publihed by NZIFST, 1983 (2010 reprint)

Eswaraiah, C., Gupta, A., Nagarajan, R., Rajavel, M. and Nandakumar, K. :'Minimization of fines generation in size reduction of coals by impact crusher'. *Fuel Processing Technology*, 89: 704-714, 2008

Fono, T. R.: 'A study on the use of palm kernel shell as friction material in automotive brake pads and linings'. Unpublished M.Sc. Thesis, Department of Mechanical Engineering, Obafemi Awolowo University, Ile-Ife. 2009

Gotsis, C., Austin, L.G., Luckie, P.T. and Shoji, K. 'Modeling of a grinding circuit with a swing-hammer mill and a twin-cone classifier'. *Powder Technology*, 42: 209-216,1985

Ibhadode, A.O.A., and Dagwa, I.M.: 'Development of asbestos–free friction lining material from palm kernel shell'. *Journal of the Brazilian Society of Mechanical Science and Engineering.* April-June 2008, XXX(2) : 166 – 173, 2008

Kayode, O.: 'A study of energy requirements in comminution of palm kernel and coconut shells using hammer mill'. Unpublished M.Sc. Thesis, Department of Mechanical Engineering, Obafemi Awolowo University, Ile-Ife. 2011

Koch, K.: 'Hammer Mills and Roller Mills'. MF-2048, *Feed Manufacturing*, Kansas State University. 2002

Koya, O.A., and Faborode, M.O.: 'Mathematical Modelling of Palm Nut Cracking based on Hertz's Theory' *Biosystems Engineering*, 91 (4), 471–478, 2005

La Nauze, R.D.: 'A review of the fluidized bed combustion of biomass'. *Journal of the Institute of Energy* : 66-76, 1987

Mohsenin, N. N.: Physical Properties of Plant and Animal Materials. Gordon and Breach Science Publishers, London, 1986

Ogunsina, B.S., Koya, O.A. and Adeosun,O.O: 'Deformation and fracture of dika nut (*Irvingia gabonensis*) under uni-axial compressive loading'. *International Agrophysics* 22 : 249-253, 2008

Oloso, A.O. and Clarke, B.: 'Some aspects of strength properties of cashew nuts'. *Journal of Agricultural Engineering Research*, 55(1): 27-43, 1993.

Potapov, A.V., and Campbell, C.S.: 'Computer simulation of impact-induced particle Breakage'. *Powder Technology*, 81: 207-218, 1994

Patumsawad, S.: 'Fluidised bed combustion of oil palm solid waste' Waste Incineration Research Center (WIRC), Department of Mechanical Engineering, King Mongku's Institute of Technology, North Bangkok, Thailand.2001

Skilling, J.: 'size reduction' http://www.chemeng.ed.ac.uk/-jennifer/solids2001/prod/node3.html .2001(Retrieved 3rd May, 2010).

Wang, C., and Mai, Y.,: 'Deformation and fracture of macadamia nuts- Part 2: Microstructure and fracture mechanics analysis of nutshell'. *International Journal of Fracture*, 69, p. 67 - 85.1994

Wang, C., Zhang, L., and Mai, Y., 'Deformation and fracture of macadamia nuts-Part 2: Deformation analysis of nut-in-shell'. *International Journal of Fracture*, 69: 51 – 65. 1995