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DEVELOPMENT AND EVALUATION OF THE PERFORMANCE OF PALM KERNEL SHELL (PKS) GRINDER

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ABSTRACT: *The suitability of grounded Palm Kernel Shell (PKS) as a friction material in formulation of non-asbestos brake lining, and component of concrete block to increase the strength is an important innovation in our recent Time. The objective can only be achieved if Palm Kernel shell is grounded to different sizes to suit the required objective. Therefore, there is need to develop a Palm kernel shell grinding machine for which this purpose is intended. The developed Palm kernel shell grinder comprises barrel, formed worm shaft, abrasive discs with mechanism for clearance adjustment, prime mover, belts, bearings, pulleys and discharge chute. The developed grinder was tested and the result showed that the machine could pulverize PKS within a range of 75 μm to 4 mm grain sizes. The report established significant potentials in the diversification of palm kernel shell from waste to sources of incomes to stakeholders most especially in the manufacture of brake lining and production of reinforce concrete block.*

KEYWORDS*:* pulverization, palm kernel shells (PKS), brake line, concrete block, waste, and wealth

INTRODUCTION

Palm Kernel Shell (PKS) is one of abundant agricultural wastes, which are not optimally used. Palm kernel shell (PKS) is the hard endocarp of palm kernel fruit that protects the palm seed. Palm Kernel Shell is recovered after extraction of palm oil from the mesocarp of the oil palm fruit; it is obtained as crushed pieces after threshing or crushing to remove the seed which is used in the production of palm kernel oil (Olutoge, 1995).

Palm kernel shells are available in large quantities in palm oil producing areas such as: Okiti-pupa, Ode-Aye farm settlement, Araromi-Obu Rubber and Oil Plantations, Irele Oil Plantations, Fashanu Farms, Abbis Farms, in Ondo State; NIFOR, Okomu farms, Nosak Farms and Iyayi Farms in Edo State; JB Farms and Royal Princess Farms in Ogun State, Nigeria; Other palm oil producing and processing countries include Ghana, Indonesia and Malaysia

Initially and from ages, palm kernel shells were disposed off after cracking to recover the nuts and as such it was considered as an agricultural waste. In 2001, Indonesia and Malaysia (the two renowned highest palm oil producing countries) produced an estimated 3.06 million metric tons of palm oil (Crutchfield, 2007). Thousands of tons of PK shell and allied products (e.g. fibre) are produced but most of these wastes do not have any meaningful utilization. They are often dumped as waste products by the concerned industry with only limited quantities of the PKS being used primarily as fuel: for domestic cooking, by the blacksmiths and goldsmith for melting iron/gold and fill materials for filling pot holes in muddy areas in some localities.

Recent research efforts have been able to shed light on suitability of ground PKS as friction material in the formulation of non-asbestos brake lining system e.g. Eco-pad (Ibhadode and Dagwa, 2008; Dagwa et al., 2012 and Fonal and Koya, 2013) emphasized the importance of PKS in increasing the strength of concrete blocks. Palm kernel shell may also be used for making terrazzo. Like all light weight aggregate, concrete made from PK shell may be useful for thermal insulation, in the making of pre-stressed concrete (Anthony, 2000). The physical and thermal properties of the shell together with its biodegradability were the figures of merit

Despite the fact that palm kernel shells are of great use in the light of the above-mentioned facts, the palm kernel shells cannot be used in its original size. There is a need to grind to smaller sizes depending on the needs; therefore, it is imperative to develop a machine that will effectively grind the palm kernel shell to appropriate sizes. The present study is channeled towards developing and evaluating the performance of a machine for grinding PKS to various sizes; this would serve as one of the means of exploring maximum utilization of the product.

Nomenclature

d_o = conveyor strip outside diameter

v_{sh} = shaft rate of conveyance

Q_{th} = theoretical load carrying capacity of the machine

A_o = Trough or barrel cross section area

m_{pks} = mass of PKS conveyed over worm shaft length

γ = specific weight of PKS (=ρ_{PKS}.g)

φ = trough loading factor

d_{st} = strip tip diameter

F = material factor

P_{conv} = conveying power

P_g = grinding power

P_{pks} = total Power of PKS machine

P_{pef} = actual power of PKS machine

l_s = length of worm shaft

R_{md} ` = mean radius of discs

μ = Discs coefficient of friction

F_{fd} = Frictional force at discs interface

F_g = effective force to cause grinding of PKS at discs interface

θ = Belt angle of contact

kW = Belt Power Rating,

d_e = equivalent pitch diameter

d_p = electric motor pulley diameter

k_b = Speed ratio

DESIGN METHODOLOGY

Design Criteria

The following criteria were considered based on size, strength of palm kernel shell, availability and suitability of fabrication materials::

Internal diameter of barrel, d_{ib} = 156.3 mm

Bulk density of Mild steel, ρ_{ms} = 7850 kg/m^3

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Clearance between barrel wall and conveyor strip = 2.15 mm

Shaft wearing plate outside diameter, d_{wp} = 60.3 mm

Electric motor speed, N_e = 1420 rpm

Bulk density of Palm kernel shell, ρ_{PKS} = 560 kg/m^3 (Fonal and Koya, 2013)

Trough loading or filling factor, φ_f = 2. 0 %

Shaft and motor pulley diameters, D_S and D_e = 300 mm / 90 mm

worm pitch, p_w= 46 mm

electric motor efficiency, η_e = 90 %

material factor, = 0.3

Design Analysis of the Palm Kernel Shell (PKS) Grinder

The design analysis was done using equations (1) to (20) and Table 2 shows the calculated values of the equations

Determination of Grinder shaft speed, N_{sh}

The speed of the worm shaft was determined using the equation (1) as:

$\frac{N_e}{N_{sh}} = \frac{D_e}{D_S}$ (Khurmi and Gupta, 2005) (1)

Hence, N_e = 426 rpm

Determination of worm mean thread diameter, d_{mtd}

The worm mean thread diameter is determined as:

$d_{mtd} = d_o - \frac{p_w}{2}$ (Khurmi and Gupta, 2005) (2)

where d_o= 150 mm to give `d_{mtd} = 127 mm

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Shaft rate of Conveyance, v_{sh}

The rate of conveyance was determined from equation (3) as

$v_{sh} = \frac{\pi d_{mtd} N_{sh}}{60}$ (Sadhu, 2004) (3)

when, d_{mtd} = 127 mm; N_{sh} = 426 rpm gives v_{sh}` = 2.833 m/s (approx)

Design of the load capacity, Q_{th}

The theoretical capacity (in mass or volumetric, Q_{th}) of the grinder was determined according to equations given by Sadhu (2004) as expressed in equation (4)

Hourly capacity, Q_{th} = 3.6qv_{sh} (4)

where the weight per metre length of the machine, q, is given by equation (5) as

q = $A_o \gamma \varphi = \frac{\pi}{4}\left(d_{st}^2 - d_{wp}^2\right)\rho_{PKS}.g\varphi$ (5)

when value are substituted yields 19.435 kN/h (0.00027 m^3/s) with q = 1.91 kg/m ()approx)

Axial mass of load on shaft (m_{PKS})

The axial mass of the load on the PKS grinder is expressed by equation (6) as:

m_{PKS}` = $\frac{q I_s}{g}$ (6)

Whem: q = 1.91 kg/m; I_s = 392 mm and g = 9.81 m/s^2; Hence m_{pks} = 0.07621 kg

Force Requirement, F_t

The total force (F_t) on the disc to initiate grinding of the PKS comprises the gravitational force, centrifugal force and frictional force

Gravitational Force, F_g

The force due to gravity (F_g) exerted on the machine as a result of the load carrying capacity of the machine is given by equation the same as the load carrying (7)

$F_g \quad = m_{PKS}.g \qquad (7)$

With m_{PKS} = 0.07621 kg; F_g = 0.747621 N

Centrifugal Force, F_{gcent}

As a result of motion, force is developed by the rotating member, according to Khurmi and Gupta (2005), the force required to spin the PKS round the abrasive discs interface for effective grinding operation is expressed by equation (8):

$$F_{gcent} = \frac{m_{PKS}V^2}{r_{mtd}} \qquad (8)$$

For $m_{PKS'}$ = 0.07621 kg; v_{sh}` = 2.833 m/s; r_{mtd} = 63.5 mm, F_{gcent} = 5.4801 N

Frictional Force, F_{fd}

Friction exists as a result of the resistance developed by the discs at their interfaces, and its magnitude depends on the relative motion of these members. The force due to ths kinetic friction (F_{fd}) is expressed by equation (9) as:

$$F_{fd} = \mu F_{cent} \qquad (9)$$

where, μ = 0.25 hence F_{fd} = 1.27 N

The total force **(F_g)** on disc required to initiate grinding of PKS is given by equation (10) as

$$F_g = m_{pks}`g + F_{cent} + F_{fd} \qquad (10)$$

when values are substituted, F_g = 7.9478 N

Torque Requirement, T_R

Torque **(T_R)** produce due to grinding of PKS (between the abrasive dics) was calculated using a modified equation (11) from Khurmi and Gupta, (2005) as:

$T_R = F_g\ R_{md}$` (11)

Where the mean radius of disc (R_{md}) of uniform pressure is obtained with equation (12) according to Khurmi and Gupta (2005) as

$$R_{md} = \frac{2}{3}\left[\frac{R_{st}^3 - R_{wp}^3}{R_{st}^2 - R_{wp}^2}\right] \quad (12)$$

when values are substituted, R_{md} = 0.11143 m (111.43 mm) and T_R = 0.8856 N

Power Requirement

The power required by the PKS grinder consists of: conveying power and grinding power

Conveying power

Prior to grinding, the machine functions as a conveyor, the effective power spent in conveying (P_{conv}) the load is given by Ibrahim and Onwualu., (2005) in equation (13) as

$$P_{conv} = 4.5\ Q_{thv}\ I_s\ \rho_{PKS,}\ g\ F \quad (13)$$

where, Q_{thv}` = 0.00083 $m^3/s$ (as determined from equation (4) above); $I_s$ = 392 mm are substituted, hence $P_{conv}$` = 2.404 kW

Grinding Power, P_g

During grinding, the PkS is grounded or pulverized as its being rotated in clearance between the fixed and movable discs. The grinding power (P_g) obtained, according to Sadhu (2004) and Ondrive (2009), with equation (14) as:

$$P_g = \frac{N_g T}{9550} \quad (14)$$

when values are substituted, P_g = 0.03951 kW

The power requirement of the PKS grinder,

$$P_{pks} = P_{conv} + P_g \quad (15)$$

$$= 2.444 \text{ kW}$$

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The actual power of the electric motor to drive the PKS Grinder was obtained using the equation given by Sadhu, (2004) as

$$P_{pef} = \frac{P_{pks}}{\eta_e} \quad (16)$$

and yields P_{pef} = 2.715 kW (3.6382 hp)

Therefore a 3.0 kW (4.02 hp) 3∅ electric motor was selected to drive the PKS grinder.

Design of Belt Drive

Belts are employed for transmitting required power A-type of V-belt was considered in this design because the design power is less than 7.5 kW together with the advantages it has over flat belt, such as slipping. From the test rig, the centre-to-centre between pulleys was measured as 470 mm. The associated parameters of the belt drive are as detailed below using equations given by Khurmi and Gupta (2005); Sadhu, (2004):

Pitch Length of Belt, L_p

The pitch length (L_p) of belt was obtained from modified equation, (17)

$$L_p = 2C + \frac{\pi}{2}(D_{sh} + D_e) + \frac{(D_{sh} - D_e)^2}{4C} \quad (17)$$

when values substituted, L_p, = 1576. mm approx)

From Table of Dimension for standard V-grooved pulley (IS: 3142 - 1965), the corresponding groove angle is 38°; likewise, the effective coefficient of friction from Table of effective coefficient of friction is 0.339

Angle of contact, $\theta = 2Cos^{-1}\left(\frac{D_{sh} - D_e}{2C}\right)$ (18)

which angle of contact = 154.18° (2.601 rad)

Determination of Belt Power Rating, kW

For A-type-belt, the power rating according to Table of Power Rating of V-belt in kW is given by equation (19) as:

k= $0.7355\left[0.61V_e^{-0.09} - \frac{26.68}{d_e} - 1.04 \times 10^{-4}V_e^2\right] V_e$ (19)

where $d_e = d_p\,k_b$ and $k_b = \frac{N_e}{sh}$

For a speed ratio of 3.33, the small diameter factor, k_b = 1.14 (IS: 2494 - 1974, p693). For L_p of 1576 mm (1600 mm), the correction factor, k_c = 0.99 (IS: 2494 - 1974, p694) and correction factor, k_d for arc of contact of 154.18^o = 0.93 (IS: 2494 – 1974, Sadhu, 2004).

Thus, the number of belts (n) required, as per "IS: 2494 - 1974" equation (21) for a particular drive, was calculated as

n = $\frac{P\,k_a}{kW\,k_c\,k_d}$ (20)

when value substituted, n = 2.64276. Therefore, 3 pieces of A type V-belt was adopted.

Table 2: Design Analysis

S/N	Equations	Equation No.	result
1	$\frac{N_g}{N_{sh}} = \frac{D_g}{D_S}$	1	426 rpm
2	$d_{mtd} = d_o - \frac{p_W}{2}$	2	127 mm
3	$v_{sh} = \frac{\pi d_{mtd} N_{sh}}{60}$	3	2.833 m/s (approx)
4	q = $A_o\gamma\varphi = \frac{\pi}{4}\left(d_{st}^2 - d_{wp}^2\right)\rho_{PKS}.g\varphi$	5	1.91 kg/m (approx..)
5	Q_{th} = 3.6qv_{sh}	4	19.435 kN/h (0.00027 m^3/s)
6	$m_{PKS}` = \frac{qI_s}{g}$	6	0.07621 kg
7	$F_g = m_{PKS}$.g	7	0.747621 N
8	$F_{gcent} = \frac{m_{PKS}V^2}{r_{mtd}}$	8	5.4801 N
9	$F_{fd} = \mu F_{cent}$	9	1.27 N

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10	$F_g = m_{pks}$`g + F_{cent} + F_{fd}	10	7.9478 N
11	$T_R = F_g\ R_{md}$	11	0.8856 N
13	$P_{conv} = 4.5 Q_{thv} l_s \rho_{PKS.}$ g F	13	2.404 kW
14	$P_g = \frac{N_g T}{9550}$	14	0.03951 kW
15	$P_{pks} = P_{conv} + P_g$	15	2.444 kW
16	$P_{pef} = \frac{P_{pks}}{\eta_e}$	16	3.0 kW (4.02 hp)
17	$L_p = 2C + \frac{\pi}{2}(D_{sh} + D_e) + \frac{(D_{sh} - D_e)^2}{4C}$	17	1576. mm approx)
18	$n = \frac{P\ k_a}{kW\ k_c\ k_d}$	20	n = 2.64276. , 3 pieces adopted

Figure1: shows the Isometric view of the developed PKS Grinding machine.

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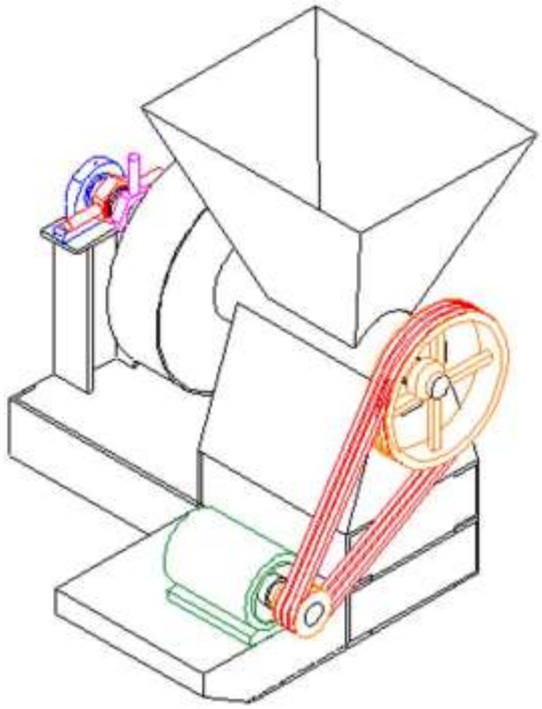

Figure1: Isometric view of the developed PKS Grinding machine

Mode of Operation

When the shell is loaded into the hopper the shell falls by gravity into the conveying chamber. The conveyor works based on principle of helix. A helix is the locus of a point which moves simultaneously around and along a cylinder; the ratio of the two movements being constant. When a shaft with helical flight rotates in a fixed trough, the contents of the trough moves along the screw worm in a direction that depends on the hand of the flights. The hand of flight and shaft's direction of rotation determine the position of the inlet and outlet chutes.-At the grinding chamber, the centrifugal action of the shaft flings the shells on the abrasive surfaces of the discs with the shell pulverizing due to rubbing action of the two discs, depending on clearance maintained between discs.

Fabrication Method, Test, Result and Discussion

Fabrication Method

The isometric and pictorial views of the developed PKS Grinder have been shown in figures 1 and 2. The PKS Grinder comprises five units: Feeding unit, Conveying unit, grinding unit, power unit and frame. The units were designed and selected based on established theories and principles as enumerated above.

The feeding unit is a square shaped hopper (of dimension 440 x440 mm at upper surface coned to 250 x250 mm at lower surface) made of 4 mm thick MS plate. It opens up and directs ungrounded PKS into the conveying unit. The conveying unit consists of a cylindrical barrel (Ø170 x 402 x 4 mm) houses a centrally mounted horizontal shaft. The shaft, centrally positioned in the barrel with flange and pillow bearings, carries oppositely placed wearing plates to which 9 pieces of worms fabricated from (Ø153 x 2 mm MS plate/strips) were welded. The worm shaft (otherwise called the conveyor shaft) facilitates the transfer of loaded PKS to the grinding chamber. The grinding unit comprises two abrasive discs, grinding housing and adjusting screw.(M20 x 200 mm) One of the abrasive discs bolted to inner wall of the grinding chamber with 4 pieces of M12 x 30 bolts and nuts whilst the other fixed with a bolt to one end of the shaft. The adjusting threaded screw centrally positioned into the grinding chamber to have a direct contact with disc mounted on the shaft enhances the clearance between the discs to be varied preference to the sizes of pulverized PKS desired.

The power unit has electrically operated motor, pulleys (driver and driven) and belts. Driver pulley is mounted on the electric motor and driven pulley on the other end of the shaft. Transmission of power from the motor was achieved with 3 pieces of A type V-belts inserted into the pulleys' grooves.

The grounded PKS leaves the grinder through the discharging chute made from 3 mm MS plate; and the whole units are coupled on frame made from 50 x 100 Universal channels (UC).

Palm kernel shell (KS) samples for this study were obtained from Agricultural Farm, Ilale, Owo, Ondo State in Nigeria. The samples were sun-dried, sieved, cleaned and prepared for grinding. The PKS Grinder, fabricated at Teco Mills and Steel Works, Owo, Ondo State, was used to carry out the test at the company factory workshop.

Tests

Palm kernel shell (KS) samples were sun-dried, sieved, cleaned and prepared for grinding. The PKS Grinder fabricated was used to carry out the test at the company factory workshop. The grinder was set into operation with known masses of PKS fed into the machine feeding hopper to determine the various sizes of grains it could produce when the discs are adjusted to give different clearances. The screw worm shaft conveyed and partially crushed the uncrushed PKS whilst the discs ground or pulverized the crushed PKS. The crushed and grounded or pulverized PKS were collected and subjected to analyses. From the analyses, the various sizes obtained were measured at Materials and Metallurgical Engineering Laboratory of The Federal University of Technology, Akure, Nigeria. The pulverized PKS was subjected to particle size distribution test according to BSE: 1377 for analysis as detailed in Table 1.

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RESULTS AND DISCUSSION OF TESTING

The PKS grinder has been produced. Most components of the machine were fabricated with locally available materials. The machine was tested using 1.0 kg mass of dry PKS and the analyses were displayed below:

A 1.0 kg of PK shell was fed into the hopper while the inlet chute of the machine was closed to prevent the PK shells falling into the conveying/grinding chambers. The machine was then switched on and the gate gradually released to allow for steady feeding of the PKS.to prevent clogging of the conveying chamber, seizure of the shaft and slipping of belts. The time taken to grind every unit mass fed into the system was noted. The procedure was repeated five (5) times for each grain size desired and the average of these five trials determined Table 1 below shows the average time of the five trials taken to obtain various grain sizes desired for a unit mass (in kg) of PKS pulverized and Fig. 1 depicts the graphical representation of the relationship between the grains sizes and their respective durations

Table1: Palm Kernel shell Grinding Test (1.0 kg)

Radius (µm)	Duration (minutes)
800	1.41
600.	2.11
425	3.04
212	6.01
180	9.02
75	17.32

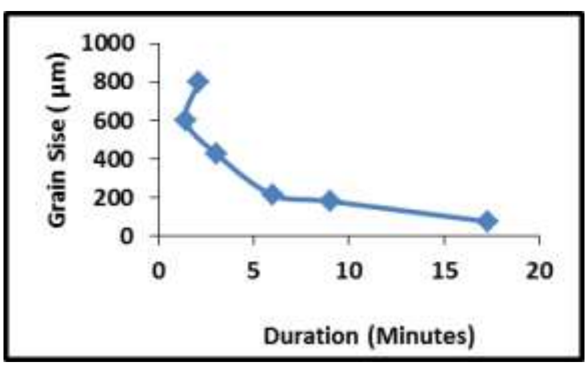

Figure2: Graph of grain size versus time of grinding

From the result of the experimental set up, the machine could pulverize PKS to different sizes but at different time range. The time required for pulverization increases as the finest of the grain sizes increase. Also, the machine could pulverize PKS to 75 µm grain size

The total cost of the fabricated PKS grinder is about N35, 000.00 (USD 206 as at April, 2015) including manufacturing cost, contingency and VAT. The amount is affordable for every concerned stakeholder

CONCLUSION AND RECOMMENDATION

Conclusion

A PKS Grinder was designed, fabricated and tested to grind or pulverize PKS. The grinder, powered by 4.02 hp (3.0 kW), 3ø electric motor, was simple enough for fabrication, operation and maintenance.

The PKS grinding machine, based on this technology, could provide employment for a minimum of 2 persons whilst at same time provide pulverized PKS of different grain sizes that could be used for producing varieties of products or applications (ceiling covers, brake pad, plastic, concrete blocks including gold and black smithers). The machine has manually threaded shaft for adjusting discs clearances to produce the required grain sizes Improvements in the design of the discs and feeding mechanism of the grinder are expected to increase the finesse of the pulverized PKS and prevent creeping of belts, seizure of shaft when loading. This developed machine could only grind palm kernel shell to sizes range between 75 µm to 800 µm.

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