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Palm Nut Cracking under Repeated Impact Load

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Abstract: Cracking a whole palm nut under repeated impact load, with the object of minimizing kernel breakage, was modeled and tested. The models were based on the conservation of energy impacted on the nut by a falling weight, or the kinetic energy of a moving nut and the strain energy required in fracturing the nutshell. One of the two models predicts the falling height required to crack a nut, in terms of stiffness, maximum deformation and size of the nut and the load cycles. The second model predicts the hurling speed required to crack a nut, in terms of stiffness, maximum deformation, mass and size of the nut and the load cycles. Experimental verification, which is in good agreement with the theory showed significant reduction in kernel breakage when palm nuts were subjected to low but repeated impact.

Key words: Palm nut, impact, cracking, fatigue, fracture

INTRODUCTION

Preserving the kernel embedded in the palm nut when cracking the nutshell is important in the subsequent palm kernel and shell separation and, in enhancing the quality of the palm kernel oil. Relevant recent investigations focused on the mechanics of cracking the palm nut using the conventional methods (Koya and Faborode, 2005) and on the separation of the product (Akubuo and Eje, 2002; Koya *et al*., 2004). The theoretical model depicted the cracking of one nut at a time in-between two stones, or in the centrifugal nutcracker, where bouncing do not occur, to predict the force requirement in breaking the palm nut.

The centrifugal nutcracker is characterized by significant kernel breakage, although, some of the nuts are discharged uncracked (Obiakor and Babatunde, 1999) Kernel breakage results partly because the kernel upon release from the nutshell rebound in the cracking chamber and is subjected to secondary impacts which induce breakage. Generally, agricultural materials including the palm nut are non-homogenous and some variations do occur in the properties of the nuts of the same size; hence, force required in breaking the nuts is not the same. Also, the interactions between adjacent nuts may obstruct the direct impingement of the individual nut to the cracking wall, so that some of the nuts are discharged uncracked.

It is reasonable to expect lower kernel breakage if the nutcracker is driven at a lower speed, to reduce the intensity of secondary impacts so that those kernels, which are released after the first impact, are not damaged. The assumption is that the kernels are discharged while the unbroken nuts are recycled. Consequently, a cracking process to subject the nut to repeated but lower impacts than the least cracking force, from static theory (Koya and Faborode, 2005) was contemplated. This approach resembles the phenomenon of fatigue failure of metals, where failure or rupture of a metal part occurs under repeated application of a load which is well below the permissible load as calculated from static stress consideration. In nonferrous metals, the fatigue strength may be as low as 20% of the tensile strength (Hamrock *et al*., 1999).

Fatigue is essentially a crack propagation process, or a cumulative effect of damage preceding material failure. In metals the material failure may be initiated, for example, by corrosion, or surface defect; in agricultural materials, crack initiation may be due to heat stress or drying, or an initial mechanical damage. Grain kernels with stress cracks break more readily upon subsequent handling than sound kernels: although, this is undesirable when whole kernels are required, it does provide a benefit in the breaking of hard nuts. Drying induced stress cracks have been observed in maize kernels (Song and Litchfield, 1994) and in Macadamia nuts (Wang and Mai, 1994; Liu *et al*., 1999). In Macadamia nut, shrinkage of the nut due to drying give rise to tensile stress in the nutshell which resulted in cracking. Therefore, the crack that caused the final fracture grew rapidly from the existing cracks, under much lower load than would crack the nut without initial crack. Once there is a cyclic plastic strain, no matter how small, eventually there will be failure.

It is common in practice, when breaking the palm nut manually in-between two stones, to impact the nut gently, two or more times, to minimize kernel breakage. Also, the mechanism of nut cracking in the conventional nutcracker is by multiple impacts from the spontaneous bouncing of the nut. Therefore, this study was undertaken to provide insight into the fracture mechanism of the palm nut broken under a falling weight or, when hurled against the cracking wall of a nutcracker repeatedly. It was assumed that the nut, upon the first impact, is deformed just beyond its elastic limit to provide the initial crack.

Mechanics of fatigue failure: Fatigue is generally understood as the gradual deterioration of a material which is subjected to repeated loads. The material undergoes significant physical changes as it is repeatedly loaded to failure.

The early stages comprise the events causing nucleation of a crack or flaw, which most likely originate at a surface. Following nucleation of the crack, it grows during the crack-propagation stage. Eventually, the crack becomes large enough for some rapid terminal mode of failure to take over such as, ductile rupture or, brittle fracture. The rate of crack growth in the crack propagation stage has been accurately quantified by fracture mechanics methods in the literature (Hamrock *et al*., 1999) but, it is of little significance in the present study.

Equivalent impact load: It is necessary to determine the minimum height to drop a weight or, the minimum speed to hurl a nut and, which will crack the nutshell at once. A lower dropping height and a lower rotational speed may then be anticipated where impact is applied repeatedly. The initial impact causes crack nucleation while subsequent impact(s) accounts for crack propagation and eventual fracture of the nutshell. This procedure will ensure that nut cracking takes place at minimum impact load, which will eliminate kernel breakage.

Drop weight: It was assumed that the nut is impacted by a load W dropping from a certain height and without bouncing on contacting the nut. The magnitude of the weight is above the maximum force that will not crack the nut irrespective of the falling height.

At the initiation of crack, assuming no energy is lost during the impact, the kinetic energy of the falling weight is transformed into elastic stain energy of the nut.

Hence,

$$W\,(h - d + \delta_{max}) = \tfrac{1}{2}\,(S\,\delta_{max})\,\delta_{max} \qquad (1)$$

Where: W in N is the falling weight, d in m is the diameter of the nut, h in m is the falling height, δ_{max} in m is the maximum deformation of the nut, when gradually compressed by a load W in N and S in Nm^{-1} is the material stiffness.

From Eq. 1,

$$h = \left[\frac{S\delta_{max}}{2W} - 1\right]\delta_{max} + d \qquad (2)$$

Force deformation curves of the two common varieties of the palm nut have been presented in a previous report (Koya and Faborode, 2005) from where the maximum deformation and material stiffness can be extracted.

The foregoing derivation assumes that the nut cracks at once but, in comparison with fatigue failure of metals, a lower falling height may be adequate if the impact is applied repeatedly. The cumulative impact energy approximately equals the work required to cause the materials to crack.

Consequently, the height at which a known weight will impact a nut for *n* times before the nut cracks is given by,

$$h = \left[\frac{S\delta^2_{max}}{2nW} - d\right] + \delta_{max} \qquad (3)$$

Centrifugal impact: The nut is hurled from a slot turning at a speed ω in rad s^{-1}, against a thick cracking ring r in m away from the centre of rotation. The equivalent impact force F in N on the nut impinging the cracking ring can be estimated by equating the kinetic energy of the moving nut with the energy absorbed upon impact, assuming that non conservative energy losses is negligible.

Thus,

$$\omega = \frac{\delta_{max}}{r}\sqrt{\frac{S}{m}} \qquad (4)$$

Similarly, when the nut is hurled repeatedly for n times, at lower speed than is required to crack it at once, the following prevails:

$$\omega = \frac{\delta_{max}}{r}\sqrt{\frac{S}{nm}} \qquad (5)$$

MATERIALS AND METHODS

Sample preparation: 'Dura' variety of the palm nut, classified as thick-shelled and most resistant to cracking (Hartley, 1977), was chosen for study. Hundred kilogram sample was drawn from a large tonnage, which has been sun-dried for commercial kernel extraction; however, the exact moisture content of the nut sample at the time of the experiment was determined.

The sample was passed through a set of sieves BS 410 (Endecotts Limited, London) with 25, 20, 14 and 10 mm apertures to grade the nuts. This was done so that, in the experiments, impacts force may be related to nut sizes.

Drop weight experiment: Using several standard weights, a suitable weight to crack the nut (dropping the weight from a reasonable height), without crushing the embedded kernel, was selected for use in the experiment. A 500 g weight was found most appropriate for use. The minimum height at which cracking took place was noted. This height was designated as the initial height.

The number of times the weight was dropped from a lower height to crack a nut was then determined. Nuts in a sample was broken one-at-a-time: some nuts breaking after the first impact while others required repeated impacts. The number of impacts was referred to as the number of cycles. The experiment was replicated five times at each of three levels below the initial height. The result of the experiment was evaluated in terms of the nut cracking efficiency and kernel breakage: the respective masses of broken nuts and broken kernels were expressed as percentages of the whole nut sample for each experimental run.

Centrifugal nutcracker: Graded nut samples were cracked in a conventional nutcracker available for the study. The nutcracker, powered by a 5 hp Lister engine, was normally driven at 1450 min^{-1} to propel the nuts against a 400 mm diameter cracker wall.

The nutcracker was then driven at lower speeds, 1100 and 800 min^{-1}, to subject the nuts to lesser impacts and to determine the number of times unbroken nuts are recycled to obtain optimum cracking efficiency. The available machine could not be driven at lower than 800 min^{-1}. Only the unbroken nuts, sorted from the discharge, were recycled in the machine. Under this investigation, the number of times unbroken nuts in a sample was recycled to crack all the nuts were referred to as the number of cycles. The cumulative cracking efficiency and kernel breakage were determined for each cycle.

Nut cracking efficiency ε_c in % was computed from the expression.

$$\varepsilon_c = \left(\frac{m_c}{m}\right) \times 100 \quad (6)$$

where, m_c in kg is the mass of broken nuts and m in kg is the total mass of the (nuts) sample.

Percentage kernel breakage K_b was defined as

$$K_b = \left(\frac{m_b}{m}\right) \times 100 \quad (7)$$

where m_b in kg is the mass of the broken kernels.

The resulting percentage cumulative cracking efficiency (when the weight was dropped a number of times to break some of the nuts in a sample, or when unbroken nuts are recycled in the nutcracker) was defined as:

$$C\varepsilon_{ci} = \left(\sum \frac{m_c}{m}\right) \times 100 \quad (8)$$

where $c\varepsilon_{cc}$ is the cumulative cracking efficiency in % after the ith cycles of impacting the unbroken nuts in the sample. The corresponding cumulative kernel breakage CK_{bi} in % was obtained from:

$$CK_{bi} = \left(\sum \frac{m_{bi}}{m}\right) \times 100 \quad (9)$$

The cumulative cracking efficiency and the cumulative kernel breakage were plotted against the number of cycles, on the same graph.

RESULTS AND DISCUSSION

The moisture content (percent wet-basis) of the nuts at the time of the experiment was 13.4%. The physical properties of the nuts, required in the verification of the theory were taken from a previous report (Koya and Faborode, 2005): the maximum elastic deformation under quasi-static compression δ_{max} is 3.2 mm; material stiffness S is 654 N mm^{-1}; the geometric mean diameter of the nut is taken as the diameter of the nut.

Verification of the impact theory: The falling heights required to crack the nutshell, dropping the 500 g weight once to four times are summarized in Table I. The predicted falling-heights from theory were compared with the experimental values. Observed deviations for all the cycles and nut sizes are generally, less than 20%. However, when nut cracking took place at the first impact, the deviation was about 50%.

The deviations may be attributed partly to the nut bouncing under impact, which was neglected in the theory. The brittle nutshell may also fracture below its elastic limit, yielding lower falling height than was expected from theory. In machine design applications, theoretical values with deviations in the range of 10 to 45% are considered good estimates (Hamrock *et al*., 1999).

The motion of the nut inside the nutcracker is random hence, the number of times the nut impings the wall cannot be readily determined. Nut cracking in the nutcracker was therefore, evaluated in terms of the cumulative cracking efficiency and kernel breakage.

Nut cracking efficiency and kernel breakage under repeated impact

Falling-weight experiment: Observed cumulative cracking efficiency and kernel breakage for the drop-weight experiment are shown in Table 2. The result

Table 1: Comparison of theoretical and experimental impact nut cracking under falling weights

Physical properties of the nuts				Required falling height, (cm)		
Sieve size retaining Nuts, (mm)	Geometric mean diameter, (mm)	Average mass, (g)	No. of cycles	Theoretical prediction	Experimental measurement	Deviation of Theory from Experiment (%)
14	20.4	5.16	1	70	35	50
			2	36	30	20
			3	24	20	20
			4	19	-	-
20	25.8	10.41	1	71	45	58
			2	36	40	10
			3	25	35	29
			4	20	25	20

-It took far more than 4 cycles to break a nut vreak a nut at heights lower than 20 cm

Table 2: Nut cracking efficiency and kernel breakage under repeated impacts from falling weight

	Cracking efficiency, (%) Falling-height (cm)						Kernel breakage. (%) Falling-height (cm)					
No. of cycles	20	25	30	35	40	45	20	25	30	35	40	45
1	30	30	30	40	80	100	0	0	0	0	30	30
2	50	90	90	90	100	-	0	0	10	10	30	-
3	60	90	90	100	-	-	0	0	10	10	-	-
4	90	100	100	-	-	-	0	10	10	-	-	-

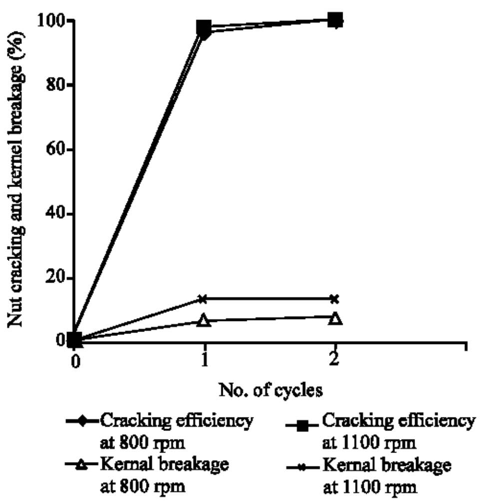

Fig. 1: Nut cracking efficiency and kernel breakage in a conventional nutcracker

indicates increase in the percentage kernel breakage with increasing falling height and loading cycles.

Dropping the weight from a height of 25 cm in two or three cycles gave the highest cracking efficiency with no kernel breakage. This height corresponds to impact energy of 1.35 J, which is less than 3.85 J required to load a nut to failure under quasi-static compression between two parallel plate (Koya and Faborode, 2005). Consequently, repeated impacts at lower falling height than would break the nut at once have resulted in eliminating kernel breakage.

Use of a conventional nutcracker: The cracking efficiency and kernel breakage using the conventional nutcracker and recycling the unbroken nut the second time, are shown in Fig. 1. Hundred percent cracking efficiency was obtained at both speeds, with 13 and 7.2% kernel breakage at the 1100 and 800 min^{-1}, respectively. In comparison, 15% cracking efficiency and 94% kernel breakage are reported in the literature (Obiakor and Babatunde, 1999) with the conventional nutcracker driven at 1450 min^{-1}. Therefore, nut cracking with repeated impacts at lower speeds has yielded better product quality than what obtains in practice.

Occurrence of kernel breakage observed in the experiment, even at the lower speed, suggests the possibility of the cumulative impact energy being in excess of the minimum energy required to fracture the nutshell. The kinetic energy of a nut striking the wall of the nutcracker, driven at 800 min^{-1}, is 1.46 J (compared with 1.23 J in the drop weight experiment) but, the nut experiences further spontaneous bouncing resulting in kernel breakage. Further investigation at lower speeds will therefore be worthwhile.

CONCLUSIONS

Energy models of nut cracking under repeated impacts of falling weights and when the nut is hurled against a stationery wall has been developed. The models predict the falling heights and the hurling speed required to crack the nut. Experimental results, where investigation was feasible, are in good agreement with the predictions.

Nut cracking under repeated impacts, recycling unbroken nut mainly yielded products of satisfactory quality judging from the observed cracking efficiency and the percentage kernel breakage.

NOTATION

C_{kbi}	Cumulative kernel breakage (%)
Ce_{ci}	Cumulative cracking efficiency (%)
d	Diameter of palm nut (m)
F	Impact force (N)
h	Falling height (m)
K_b	Percentage kernel breakage (%)
m	Mass of nuts sample (kg)
m_b	Mass of broken kernel (kg)
m_c	Mass of broken nuts (kg)
n	Number of cycles
r	Radius of nutcraker's wall (m)
S	Stiffness modulus ($N\ m^{-1}$)
W	Falling weight (N)
δ_{max}	Maximum deformation of palm nut (m)
ϵ_c	Cracking efficiency (%)

REFERENCES

Akubuo, C.O. and B.E. Eje, 2002. Palm kernel and shell separator. Biosys. Eng., 81: 193-1999.

Hamrock, B.J., B.O. Jacobson and S.R. Schmid, 1999. Fundamentals of Machine Elements. Published by McGraw-Hill Company, pp: 257-272.

Hartley, C.W.S., 1977. The Oil-Palm. Longman Publishers, London.

Koya, O.A., A. Idowu and M.O. Faborode, 2004. Some properties of palm kernel and shell relevant in nut cracking and product separation, J. Agric. Eng. Technol., 12: 27-39.

Koya, O.A. and M.O. Faborode, 2005. Mathematical modelling of palm nut cracking based on Hertz's theory. Biosys. Eng., 91: 471-478.

Liu, R., C.H. Wang and R.G. Bathgate, 1999. Fracture analysis of cracked macademia nutshells under contact load between two rigid plates. J. Agric. Eng. Res., 74: 243-250.

Obiakor, S.I. and O.O. Babatunde, 1999. Development and testing of the NCAM centrifugal palm nut cracker. AGRIMECH Res. Inform. Bull. (NCAM), Ilorin, Nigeria.

Song, H.P. and J.B. Litchfield, 1994. Measurement of stress cracking in maize kernels by magnetic resonance imaging. J. Agric. Eng. Res., 57: 109-118.

Wang, C.H. and Y.W. Mai, 1994. Deformation and fracture of macadamia nuts-part 2: Microstructure and fracture mechanics analysis of nutshell. Intl. J. Fracture, 69: 67:85.