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International Journal of Research Publication and Reviews

Journal homepage: www.ijrpr.com ISSN 2582-7421

Design and Fabrication of a Hammer Mill for Domestic Use

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ABSTRACT

A hammer mill for domestic use was developed and constructed at the Department of Agricultural and Bio-Environmental Engineering, The Federal Polytechnic, Ado-Ekiti. The machine comprises a frame/stand, hammer/beater, milling chamber with a rotating shaft, hopper, and an electric motor. Powered by a 2.25 kW (3 hp) electric motor running at 2800 rpm, the hammer mill features three hammers arranged at 120-degree spacing on the rotor. During dry cassava milling, it achieves a capacity of 34.5 kg/hr, 15.2 kg/hr for dry plantain, and 22.5 kg/hr for dry yam. The milling efficiency is 87.8% for dry cassava, 88.3% for dry plantain, and 92.9% for dry yam.

Keywords: Hammer mill, Domestic, Hammer, Rotating shaft

1. Introduction

A hammer mill is a high-speed machine that utilizes hammers and cutters to crush, grind, chip, or shred solid waste (Yancey *et al.,* 2013; Mugabi *et al.,* 2019). These durable utility grinders can handle most free-flowing materials (Martin, 1985). Hammer mills operate based on the principle that materials will grind or crush upon impact with the hammers (Ibrahim *et al.,* 2019).

A hammer mill is fed material from the top, allowing it to fall into the grinding chamber due to gravity (Elashhab *et al.,* 2015**;** Ibrahim *et al.,* 2019). Grinding occurs through repeated contact with the chamber walls and particle-to-particle interactions. The material remains in the chamber until it reaches the desired size and can pass through the perforated screen covering the lower half (Baker, 2009**;** Adejugbe *et al.,* 2023). Hammer mills are designed to crush and refine compact farm produce. They are used for various tasks, including turning dry yam into powder, cassava tubes into flour, maize into fine particles, and even crushing dry bone for livestock feed (Jayne and Rubey, 1993). Hammer mills can be made of mild steel or stainless material (Ajayi *et al.,* 2019), depending on their intended use. They can be powered by electricity, petrol, or diesel engines, with capacities ranging from 3 to 5 horsepower for medium-sized mills and greater capacities as needed (Bucham *et al.,* 2022). A portable hammer mill offers an affordable, user-friendly solution for domestic milling, similar to household blenders and appliances.

2. Materials and Methods

2.1 Description of the Hammer Mill

The hammer mill for domestic use was developed at the Department of Agricultural and Bio-Environmental Engineering, The Federal Polytechnic, Ado-Ekiti, Ekiti State. The features of the machine include frame, hopper, hammer, screen, flange couplings.

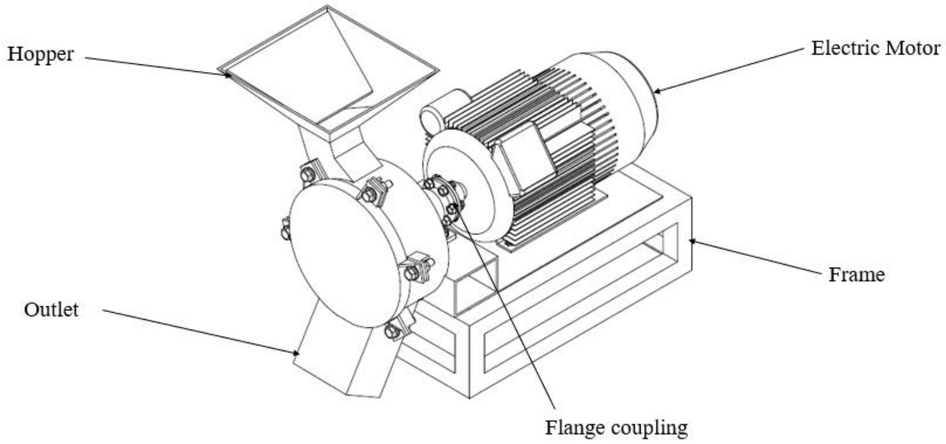

Fig. 1: Isometric view of the hammer mill

2.2 Design Considerations

The design of a hammer mill for domestic use is based on the following considerations:

(i) The machine is simple in design with the use of locally available materials for the fabrication of the component parts.

(ii) The ease of fabrication of the component parts with simple joinery methods.

(iii) Affordability of the machine to small-holder farmers.

(iv) The machine is easy to operate.

(v) Rigidity and Stability

2.3 Determination of shaft speed

The shaft speed has the same speed with the recommended electric motor. An electric motor (3hp) with the speed of 2800rpm was selected.

Electric motor speed (2800rmp) = Shaft speed (2800rpm)

2.4 Determination of torque acting on the shaft

The torque acting on the shaft was determined using the equation:

Torque = $\frac{P \times 1000 \times 60}{2\pi N}$

Where P is power of the electric motor

N is speed of shaft

The torque acting on the shaft is 7.67 Nm

2.5 Determination of Capacity of Hopper

The capacity of hopper was determined using the equation:

M_h = volume of hopper (pyramid) × density of dry cassava.

Volume of hopper (pyramid) = $\frac{h}{3} \times (B_1 + B_2) + \sqrt{(B_1 \times B_2)}$

2.6 Mass of cassava

The mass of cassava is determined using the equation:

Mass = density of cassava × total volume of hopper

NOTE: Density of materials to be used for the testing performance is:

1. Dry cassava = 0.87g/cm^3 (Romuli *et al.*, 2017)

2. Dry yam = 0.63g/cm^3 (Falade and Onyeoziri, 2012)

3. Dry plantain = 0.56g/cm^3 (Ayorinde *et al.,* 2013)

The highest density was selected i.e. density of dry cassava (0.87g/cm^3).

The mass of cassava is determined as $0.2424\ kg$

2.7 Mass of hammerThe mass of hammer is determined using the equation:

The mass of hammer is determined as 0.75kg.

2.8 The force acting on the shaft (F)

The force acting on the shaft is determined using the equation:

F = m × a

F = (mass of hammer + mass of cassava) × 9.81.

The force acting on the shaft is determined as 10N

2.9 Determination of shaft diameter

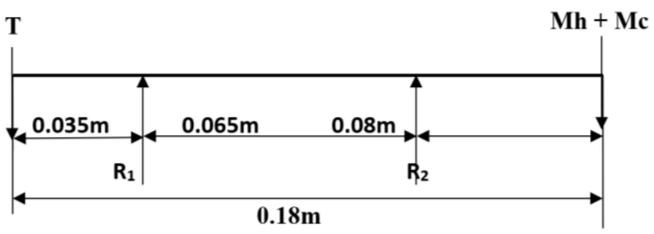

Fig 2: Vertical forces acting on the shaft

Where;

T=Torque

Mh=Mass of hammer

Mc=Mass of cassava

Therefore, the maximum bending moment = −51.2Nm

To determine the Torsional moment (Mt), using the below relationship;

M_t = maximum tensional moment

$M_t \frac{p}{2\pi n}$

Where;

P = power rating of the electric motor = 2.25kW

N = 2800rpm (numbers of revolution of the electric motor per minute)

The maximum torsional moment is 7.67 Nm

The shaft diameter was determined using Universal Formula

$d^3 = \frac{16}{\pi S_s}\sqrt{(k_b M_b)^2 + (k_t M_t)^2}$

where,

$d =$ diameter of the shaft (m)

M_b = Bending moment (Nm)

M_t = Torsional moment (Nm)

k_b = combined shock and fatigue factor applied to bending moment

k_t = combined shock and fatigue factor applied to torsional moment

S_s = allowable stress = 40 Nm^{-2} (for shaft with key way)

Shaft diameter is determined as 24.4mm

Therefore, solid shaft diameter 30mm nearest to the calculated diameter was selected

3. Fabrication of the Machine

The length, breadth, and height of the frame was measured with measuring tape and marked with a scriber. The angle iron was cut with cutting machine into the required sizes and then welded together with electric arc welding transformer.

The hammer was cut with shear cutting machine and fabricated from a stainless-steel plate with dimensions 75.5mm × 6mm, held in position by a permanent joint, with 120^0 distance between the hammers. The hammer was then sharpened and smoothed with grinding machine. The hammers were welded to the hollow splined cone together with electric arc welding transformer.

The frame/stand was constructed by welding the appropriate side to each other. The two pillow bearing, one was fixed at the back of the milling chamber while the other was fixed on the top of the frame. The hammers were welded to the shaft rotor, with a hole drilled on the rotor as a key. The two flange couplings were connected to both the machine shaft and electric motor shaft, and then bolted together with bolts and nuts.

Fig 3: Fabricated hammer mill

4. Test Results

Three different materials dry cassava, dry plantain, and dry yam were used to test the machine. The materials were weighed before introducing into the machine. The machine was then put on and a known quality of each material was introduced through the hopper to the machine. The milled material was collected through the outlet with time for operation noted and recorded. The machine was allowed to run free in order to make sure that last milling materials was out.

Milling efficiency and milling capacity were determined for the three different materials.

Table 1: Test results for the hammer mill

Test parameters	Result
milling capacity on dry cassava	34.5kg/hr
milling capacity on dry plantain	15.2kg/hr
milling capacity on dry yam	15.2kg/hr
milling efficiency on dry cassava	87.8%

milling efficiency on dry plantain	88.3%
milling efficiency on dry yam	92.9%

5. Conclusions

A hammer mill was designed and fabricated using locally sourced materials for domestic use. The machine was designed to improve the efficiency and durability by using a stainless-steel material for the hammers to prevent contamination and corrosion. Flange couplings was also introduced as a direct contact between the machine and electric motor for high torque transmitting capacity. The machine was constructed in such a way that it is portable with less weight and moderate size for easy transportation within the house. The test carried out on the machine using dried cassava, dried plantain, and dried yam gave a satisfactory performance. All the parts of the machine were fabricated from mild steel material.

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