Design and Development of a Petrol-Powered Hammer Mill Machine

J. A. Olowonubi [a*], I. T. Adejugbe [a], S. A. Fatounde [a], J. O. Aigbovbiosa [a], O. A. Oyegunwa [a], O. Komolafe [a] and A. K. Ogunkoya [a]

[a] *Engineering Materials Development Institute, Km 4, Ondo Road, Akure, Ondo State, Nigeria.*

Authors' contributions

This work was carried out in collaboration among all authors. Author JAO wrote the first draft of this manuscript and played a part role in the modelling of the machine. Author ITA wrote the second draft of this manuscript and was in charge of the working drawings of the machine both as a model and in the manuscript. Author JOA played a pivotal role in the development of the machine on the workshop floor and supervised the development of the machine on the workshop floor. Author OK approved the drawing on the workshop floor. Author AKO was the final supervisor of the modelling and development. All authors read and approved the final manuscript.

Original Research Article

ABSTRACT

A conventional hammer mill is a device consisting of a rotating head with free- swinging hammers, which reduce rock, grains or similarly hard objects to a predetermined size through a perforated screen. Hammer mills can be used for grinding laterite sand in its not-so-fine form into a finer/smaller form for sand production for the building/housing sector. This project is focused on the design, development, and testing of a hammer mill that has a small scale production capability for usage by small and medium scale (SME's). The grinding process is achieved by the use of a hammer in beating the material fed into fine particles; the fineness aimed depends on the detachable screen with aperture sizes ranging from 87μm to 2 mm. The conceptual design was

---

*Corresponding author: E-mail: olowonubijohn@gmail.com;

based on the principle of design by analysis. The methodology adopted was to examine the most critical defects of conventional hammer mills and provide solutions. The major components of the new hammer mill are Inlet tray, Throat, Magnetic chamber, Rotor, Crushing chamber, Hammer mill body, Hammers/Beaters, Screen, Bearings, Discharge, Table or stand, Mechanical drive, Pulleys, The simple aim of this paper is to develop a hammer mill machine that will enhance the efficient grinding operation of laterite rock into a sandy profile to be used in the construction/housing sector. This paper presents the design of an efficient hammer mill machine that was developed with locally sourced materials with ease of maintenance amongst other advantages. The machine is driven by an electric motor of 7.5kW at a speed of 1440rpm and with the appropriate pulley ratio, the machine operated at a speed of 4320RPM with an operating rate of 250kg/hour. Several fabrication techniques such as welding, machining, etc. are adopted for the fabrication of the machine. Dry rocky laterite sample was tested with the machine for operational effectiveness and the result shows that the machine has a grinding capacity of 250kg/hr and grinding efficiency 0f 98.2%. The fabricated laterite grinding machine performed well with high sieving efficiency, reliability, durability with an estimated cost of 965,000.00 Nigerian Naira.

The study was carried out in Akure, Ondo State, Nigeria. A performance evaluation was carried out on the machine and the grinding efficiency of 94.4% was achieved.

1. INTRODUCTION

"Laterite is a highly weathered material, rich in secondary oxides of iron, aluminium, or both. Laterites are produced when there is an intensive and long lasting tropical rock weathering which is amplified by high rainfall and elevated temperatures. We must also note that they are an important source of many metal ores, particularly nickel, cobalt, manganese, iron and aluminium" [1].

Fig. 1. Sample of laterite

"Laterite, known as 'green' or environmental friendly construction materials can easily be re-cycled, have low energy consumption and toxicity in production and applications. In construction, environmental designs and sciences, building professionals have the responsibility to ensure that laterite used is environmentally friendly and sustainable. One of the main aims of Millennium Development Goals is to provide friendly environmental sustainable infrastructures. It is evident that environment is adversely affected, trees are cut down bushes, grasses are cleared, and soils are excavated randomly while construction activities generate noise and environmental pollution" [2]. "Laterite has been the most widely known and used construction materials in construction industry, are successfully used as sustainable construction materials in various aspects of civil and building construction projects. The material is also employed in the construction of rural feeder roads, townships roads, intercity link roads, dams, airport runways, highways roads. The areas of use of laterite are: Agriculture, Building blocks, Road building, Water supply, and Waste water treatment" [3].

"The diverse usefulness of Laterite and the various challenges encountered during grinding has called for an urgent need to improve the processing means in laterite grinding. Crushing is an integral part of the combination flow sheet for laterite processing operations and it is critical for the preparation of ore for downstream processing" [4]. To meet up with the demand of properly crushed sand by the building sector and its customers, a mechanically fortified method that is effective, made from local raw materials and reasonably cheap needs to be developed in other to improve on the previous designs and fabrications of laterite grinding machine [5]. The hammer mill in this work was developed from locally sourced materials. The machine is suitable for grinding laterite and finds application in feed mill and pharmaceutical industries [6]. The crushing is achieved using a set of hammers in a crushing chamber which beats the laterite

fed through the hopper against a grinding screen into smaller particles [7].

Milling of dried laterite rock particles into finer bulk material particles is an age long practice which has been carried out using various methods which include earth stones, forced beating using human effort, mechanical devices by attrition and blenders. Each of these methods has had their various advantages and set back. Increased demand for various materials arising from a growing human population around the world has necessitated technological exploration and improved productivity. This has led to the proliferation of new machineries and optimization of existing ones. The hammer mill in this regard is a product of improved methods of bulk material sand processing into finer particles by pulverization, grinding and sieving through a solid mesh or forced draft [8].

The machine consists of a shaft on which a set of free swinging metal weights are attached. It also consists of a loading hopper, milling chamber, bearings and a motor which is connected to one end of the shaft via a pulley and belt and drives (rotates) the shaft and hammers at high speed to effect milling of the laterite rock particles. Modern day hammer mills are mostly imported from the developed nations into other developing countries like Nigeria hence; are quite expensive to acquire, and maintain [9]. Nigeria is a country with vast arable lands mostly around the rural areas with under-utilization of the vast land mass for application in the construction and housing sector. The hammer mill is one of such mechanical system which should be amenable to such explorers of that sector. While the imported hammer mills are too expensive for their acquisition, other locally available or improvised methods are either too tedious to use, or are froth with reoccurring problem. Conventional and many locally made hammer mills that have found usage in many parts of the communities in the country where such land mass is available and this has been observed to have many setbacks and have been a basis for the design of improved and optimized local models of the machine [3].

Documented setbacks of many of the existing locally made hammer mills have been reported by various researchers and they include the followings; Wear and corrosion as a major cause of sieve screen holes' enlargement or burst which then allows passage of larger than desired particles to pass through [4]. After several hours of milling operation, the sieve holes are clogged with a consequential reduction in its efficiency and operating capacity. There is tendency of a build-up of moisture which makes the materials wet and become elastic and therefore absorb most of the impact energy of the hammer without actually breaking down to smaller particles. In a bid to proffer solution to the setbacks identified, the authors designed a petrol powered hammer mill with a dimensionally controlled open gate endless sieve to solve the problem of sieve bust and clogging [2]. "The authors cited some drawbacks in conventional hammer mill design which include moisture build up, sieve deterioration, particle size limitation greater than 400μm, high cost of screen maintenance and environmental pollution resulting from bulk material sand release. The focus of this developed machine was to have a machine produced out of locally sourced materials for the production in order to reduce cost of production and maintenance. He also asserted that the machine could be dis-assembled to ease maintenance" [5].

1.1 Methods of Crushing Laterite

"Crushing is an integral part of the comminution flow sheet for mineral processing operations and is critical for the preparation of ore for downstream processing. The selection of the right crushing equipment for a specific purpose is influenced by many factors some of which are downstream of the crushing plant. Mineral processing is a complex operation. The principal procedure is crushing, that is the size reduction in the size of the fragmented rocks so that it can be rendered to another stage for further processing. In ancient time, the mineral were crushed between two stones or the use of metals with stones, but the invention of modern systems employing steel materials such as hammers mill has revolutionize the processing of minerals in a small scale and large scale capacity" [6].

"There are different types of machines that can be used for to reduce the sizes of materials. These are Hammer mill, Gyratory crusher, Jaw crusher, Ball mill, Burr mill and many others. Thus, of all the crushing machines available, the Gyratory crusher, jaw crushers and the hammer mill are the most widely used in mineral processing industries because of its desirable characteristics which include ability to handle a wide variety of raw materials, ability to handle hard stray objects and its robustness. In the big mining industry, four processes are adopted for

continuous size reduction; these are the primary, secondary, tertiary and the quaternary crushing operations" [1,10]. "There are four basic ways of reducing the size of materials in the mineral processing industry, these are impact, attrition, shear or compression and most crushers employs a combination of these crushing methods" [7].

"Crushing as an operation is becoming a well-known operation in the Nigerian mineral industry, as a result of the popularity of the minerals deposits that abound in the country and the importance of these mineral resources in the economic development of the country" [9]. "The minerals and mining industry has been unable to meet up with the demand of this housing, manufacturing and construction companies due to low supply of their demand as a result of no small scale mining firm to supplement the existing large scale mining firm [11]. Crushing plays a pivotal position in the combination flow sheet for laterite processing. The fabricated machine grinds laterite of medium lumps at the rate of 100kg/hr and was designed and developed to be rigid, efficient and portable to aid its movement to any site where it might be needed" [8].

1.2 Aim of the Project

The aim of this project is to develop an efficient hammer mill suitable for laterite grinding out of locally sourced materials and at a reduced production and maintenance cost.

1.3 Objectives of the Project

The objectives of this project is to:-

1. develop an efficient Laterite Hammer Mill, and
2. carry out performance evaluation of the machine developed in order to determine its functional requirements

1.4 Justification

The problems associated with the existing process of grinding laterite are enumerated thus:-

1. The old method of laterite grinding is extremely time-consuming with little output and labor intensive.
2. Cost of buying imported machine is high.

Therefore, the project is to provide an alternative means to the problems highlighted above while still placing emphasis on efficiency of the machine.

1.5 Research Methodology

Extensive review of literatures on laterite, methods of grinding and existing machines is carried out. Literatures on laterite grinding machines were read and used. Some experimental grinding processes were done and literature on construction and fabrication techniques was also consulted so as to get a good development which is cheap, made from local materials and with good aesthetics.

The Conceptual design: The conceptual design was based on the principle of design by analysis. The methodology was to introduce special features into the hammer mill so that certain lapses noticed in the convectional hammer mill is reduced to a bearable level. This usually occurs in an enclosed chamber called the crushing chamber. The physical and mechanical properties of the material to be crushed were studied as this would help immensely in the design of various components of the rotor. The engineering properties and some other important parameters must be well known as they are the main factors considered before design of the machine.

The assembly of the machine was also researched and the materials selection software (GRANTA) was adequately used. Evaluation and testing of the project work was carried out under a controlled environment of the institute's workshop so that the behaviour of the machine was properly ascertained and its behaviour under other conditions can be predicted.

Vast knowledge of various CAD software (ProEngineer, AutoCAD and Autodesk Inventor) was adequately used in the Modeling and Simulation of this machine and the force analysis was carried out to know its performance under different loading conditions.

1.6 Significance of the Project

The manual method of laterite grinding is very slow and burdensome which apparently leads to the wastage of resources, low output and time consumption. This work aims at increased productivity, optimal performance of the machine

and affordability by the Small and Medium scale industries in the country.

1.7 Design Considerations

The design was carried out on the basics of the safety of the operator. Some other major hazards which may arise in the course of crushing were properly put into consideration. The deflection of the hammers while in operation was also considered in the design. Swinging instead of stiff hammers was used to avoid the rotor or the hammers from getting stocked in case a hammer comes in contact with a material it cannot break on first impact.

1.7.1 Basic design

Determination of Shaft Speed

To calculate the shaft speed the following parameters are used.

$$\frac{D_1}{D_2} = \frac{N_2}{N_1} \tag{1}$$

Where

N_1 = revolution of the smaller pulley, rpm
N_2 = revolution of the larger pulley rpm
D_1 = diameter of smaller pulley, mm
D_2 = diameter of larger pulley, mm

This shaft speed is known when there is no slip condition of the belt and the pulley. When slip and creep condition is present, the value (913.5rpm) is reduced by 4% (5).

Determination of Nominal Length of the Belt

$$L = 2C + \frac{\pi}{2}(D_1 + D_2) + \left(\frac{D_1 - D_2}{4C}\right)^2 \tag{2}$$

Where,

L = Length of the belt, mm
C = Centre distance between larger pulley and the smaller one, mm
Centre distance minimum, C_{min} was calculated using:

$$C_{min} = 0.55(D_1 + D_2) + T \tag{3}$$

And Centre distance maximum:

$$C_{max} = 2(D_1 + D_2) \tag{4}$$

T = Nominal belt thickness
D_1 = Larger pulley diameter
D_2 = Smaller pulley diameter

Determination of Belt Contact Angle

The belt contact angle is given by equation

$$\sin^{-1} \beta = \frac{(R-r)}{C} \tag{5}$$

Where,

R = radius of the large pulley, mm
r = radius of the smaller pulley, mm

Determination of the Belt Tension

$$T_2 = \frac{(T_1 - MV_2)}{\exp\left[\frac{\mu\alpha}{\sin\frac{1}{2}\theta}\right]} \tag{6}$$

$$T_2 = SA \tag{7}$$

Where

S = the maximum permissible belt stress, MN/m^2
A = Area of belt

Determination of the Torque & Power Transmitted for the Shaft

$$POWER = (T_1 - T_2)V \tag{8a}$$

$$T_r = (T_1 - T_2)V \tag{8b}$$

Where,

T_r = Resultant Torque
T_1 & T_2 = Tension in the belt, N
R = Radius of bigger pulley, mm

Determination of Hammer Weight

$$W_h = M_n g \tag{9a}$$

Material = Mild Steel

Density = 7.85g/cm3

$$Density = \frac{Mass}{Volume} \left(kg/m^3\right) \tag{9b}$$

Determination Maximum Power Transmissible (Kw)

The maximum power, which the belt can transmit, is given by:

$$P = \frac{0.45}{V^{0.09}}\left[\frac{19.62}{D_o} + 0.765 + 10^{-4}V^2\right]V \qquad (10)$$

Where D_o = equivalent pitch diameter (mm). If F_b is the small diameter factor to account for the arc of contact, then

$$D_o = dF_b \qquad (11)$$

where d = diameter of the driver pulley (mm).

Determination of Hammer Shaft Diameter

$$\sigma_s \text{ (allowable)} = \frac{M_b Y_{max}}{I} \qquad (12)$$

$$\frac{I}{Y_{max}} = Z = \sigma_s = \frac{M_b}{Z} \qquad (13)$$

Where

Y_{max} = Distance from neutral axis to outer fibers
I = Moment of inertia
Z = Section modulus

For solid round bar

Hopper Design

Hopper design is based on a common criterion, which is required for it to function. This criterion is called the *"Angle of Repose"*. Angle of repose is defined as the angle of friction of rest. The hopper designed is a gravity discharge one, and the recommended angle of repose for gravity discharge ranges between 15^0 and 25^0

The volume was estimated from equation;

$$V = \frac{h}{3}\left(A + a + \sqrt{Aa}\right) \qquad (14)$$

Where:

h = perpendicular height (mm);
A = Area of the upper opening (mm^2);
a = area of the lower opening (mm^2).

Note that the slant height, l is obtained from the relation,

$$h = l\cos\phi \qquad (15)$$

Where ϕ is the angle of repose.

Table 1. Design specifications (authors' estimate; 2018)

Components	Assumed Parameters	Design Parameters
Hopper	h=280mm, A= 129,600mm^2, a=12,100mm^2	V=16.92x10^{6}mm
Speed Ratio	N_1 = 2600 rpm; N_2 = 2267 rpm; d = 102mm	D = 117mm
maximum power	F_b = 1.0; d = 0.102m	P = 4.85kW
Prime Mover	From Shaft, Pulley and capacity design	2,600 rpm, 4.85 kW
Width of pulley	t = 11mm	W $\cong$ 14mm
Belt Number (N)	F_d = 0.98; F_c = 0.8; F_a= 1.2; P = 4.85kW	N = 2.024
Tension, T_1 and T_2	W_1 = 13mm; β = 175^0; θ = 34^0; W_2= 4.89mm; h = 21.26mm; V = 5.73ms^{-1}	A = 7.16x10^{-5}m^2; T_1 = 143.2N; α_1 =175^0; α_2 = 185^0; Cl_1 = 64.89; Cl_2=83.02; T_2 = 4.45N
Diameter, d, of shaft	Mb = 69.27Nm; Mt = 10.41Nm; Kb= 1.5; K_t = 1.0; S_s = 55x10^6 N/m^2	d = 35mm

2. MATERIALS SELECTION PROCEDURE

The considerations contained in this work are aimed at meeting the desired standard as expected for a laterite grinding machine. This were the Materials selection procedure that was carried out before each materials was considered appropriate for usage and a final selection was made. The selection of materials for various parts of machine is based on the following factors.

- Strength of the material and rigidity of the machine,
- Ease of fabrication
- Durability
- Cost of material and hence production cost with consumer in view,
- Availability of the material locally and ease in obtaining them,
- Economy / feasibility

Table 2. Materials selection procedure

S/N	Machine Component	Criteria for Selection	Most Suitable Materials	Materials Selected	Reason for Selection
1.	Shaft	Strength, machine, surface finish, weight, cost, availability.	Mild steel, cast iron	Mild steel	High strength and light weight
2.	Pulley	Weight, good wearing property, availability	Mild steel, cast iron	Mild steel	Availability and weight
3.	Belt Guard	Strength, machinability, surface finish, weight	Mild steel, carbon steel	Mild steel	Surface finish, light weight
4.	Grinding Unit	Weight, wear resistance, availability	Mild Steel, Galvanised Steel, stainless steel	Mild Steel	Cost and availability
5.	Bearing	Self-aligning bearing	Standard part	Pillow block bearing	Self-aligning
6.	Hopper	Weight, good wearing property, availability	Mild Steel, Galvanised Steel and stainless.	Mild Steel	Cost and availability
7.	Frame (grinding Unit stand and Diesel Engine stand)	Strength, Ability to withstand impact load/stress, availability	Mild Steel, Galvanised Steel	Mild Steel	Strength, Ability to withstand impact load/stress and availability

3. RESULTS AND DISCUSSION

3.1 Machine Description

The machine is being driven by a prime mover with a rated power output of 4.85 kW and a speed of 2600 RPM. The prime mover is connected to the shaft driving the hammers by a Pulley - belt drive system. The machine comprises of four major parts, the hopper, the crushing chamber, machine frame and the prime mover. The laterite is fed into the hopper, with the feed control locked. The feed control is then released gradually to allow flow of laterite into the crushing chamber. There in the crushing chamber, the laterite is been beaten by set of hammer mills to reduce the sizes of the feed laterite. The reduced laterite flows out of the crushing chamber through the delivery chute connected to the bottom of the crushing chamber.

3.2 Diesel Engine

The Diesel Engine was selected based on the speed and power output required for the machine. The specifications of the diesel engine as available on its tag are:

Table 3. Diesel engine specifications

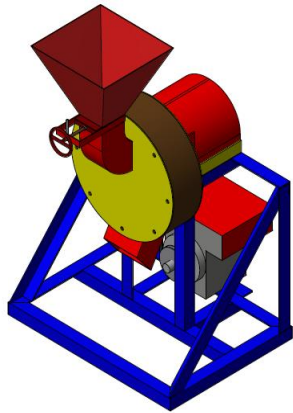| Description	Data
Power	4.85 Kw
Speed	2600rpm

Fig. 2. 3D Model of the Hammer Mill

Fig. 3. Picture of the Developed Hammer Mill

3.3 Performance Evaluation

Laterite was used for testing the machine, the testing apparatus are stop watch and weighing balance. 10kg of laterite sample was fed into the crushing chamber of the machine through the feed hopper. The time taken to crush the sample i.e. the sample to fully discharge was noted and the weight of the crushed sample taken. The process was repeated for samples of weight 20kg, 30kg, 40kg and 50kg, the results obtained are as follows;

The performance criteria tested for, were;

a. Grinding capacity (GC), and
b. Grinding efficiency (GE).

Grinding Capacity (GC): The grinding capacity is the rate at which the machine grinds in kilogram per hour and this was calculated as;

$$GC = \frac{M}{t}$$

Where;

GC = Grinding Capacity (kg/hr)
M = Average mass of laterite loaded into the hopper (kg)
T = Average time taken to complete the grinding (hr.)

Considering the results obtained from the performance of the machine, the capacity of the machine (GC) is obtained as follows;

$$GC = \frac{M}{t}$$

$$GC = \frac{147.3}{1.428}$$

$$GC = 103.15\text{kg/hr} \approx 100\text{kg/hr}$$

This means this machine has the capacity of processing 100kg/hr of laterite which makes it a good machine for usage.

Grinding Efficiency (GE): This is defined as the ratio of crushed laterite sand to the mass of laterite loaded to the machine and is calculated as;

Table 4. Performance evaluation of machine

Trials/Test	Weight input (kg)	Time Taken (min)	Weight output (kg)
1	10	6	9.3
2	20	10.5	19
3	30	16.7	29.5
4	40	23.3	40
5	50	29.2	49.5
Average	**150**	**85.7**	**147.3**

$$GE = \frac{\text{average mass of crushed laterite}}{\text{average mass of laterite loaded}} \times 100\%$$

Where; $GE = Grinding\ efficiency$
$average\ mass\ of\ crushed\ laterite = 147.3 kg$
$average\ mass\ of\ laterite\ loaded = 150 kg$

$$GE = \frac{147.3 \text{kg}}{150 \text{kg}} \times 100\%$$

$$GE = 98.2\%$$

4. CONCLUSION

The hammer mill designed and fabricated in this work was aimed at reducing the lump sizes of laterite to finer particle for interlocking brick making. The performance evaluation of the produced machine showed it works at an efficiency of 98.2%, thereby making the fabricated laterite grinder efficient. The materials selected for the development of the machine are locally available thereby making the machine easy assessable and affordable.

The environmental pollution associated with the use of conventional hammer mills is virtually eliminated in the new hammer mill. Thus there is no health hazard experienced by the operator of the new machine. Furthermore, the new hammer mill would reduce working losses, reduce production downtime, enhances greater consumer choice and it reflects a more effective response to changing market requirements and increases better working capability of the Machine

ACKNOWLEDGEMENTS

COMPETING INTERESTS

Authors have declared that no competing interests exist.

REFERENCES

1. Dance A. The importance of primary crushing in mill feed size optimization; 2011

2. Proceedings International Autogenous and Semi-Autogenous Grinding Technology 2011, eds. D.J Barrat. M.J Allan and A.I Muller(Unpublished).

3. Flavel MD, Rimmer HW. Particle breakage in an impact crushing environment. 2011;20.

4. Ajaka EO, Adesina A. Design, fabrication and testing of a laboratory size hammer mill. International Journal of Engineering and Advance Technology Studies. 2014;2(2):11-21.

5. Brennan JG, Butter JR, Cowell NO, Lilly AE. Food engineering operations. Applied Science Publisher Ltd London; 2009.

6. Spolt MF. Design of Machines Element, 6th ed. Prentice Hall, New Delhi, India; 2008.

7. Hall A, Holowenko A, Laughlin H. Theory and problem of machine design. tata McGraw- Hill Publishing Company ltd. New Delhi. 4th Edition. 2004;6-89.

8. Hannah J, Stephens R. Advanced theory and examples in mechanics of machines. Edward Arnold Ltd, New Delhi, Ist Edition 6. 2004;77-819.

9. Lemougna PN, Melo UFC, Kamseu E, Tchamba AB. Laterite based stabilized products for sustainable building applications in tropical countries: Review and prospects for the case of Cameroon: Sustainability. 2011;3(1):293-305.
   DOI: 10.3390 /su3010293

10. Martyn Shuttleworth. Defining a Research Problem; 2008. retrieved from explorable.com:
    http://explorable.com/defining-a-researchproblem.

11. Khurmi S, Gupta JK. A textbook on Machine Design; 2008.