__Original Research Article__

DESIGN AND DEVELOPMENT OF A PETROL-POWERED HAMMER MILL MACHINE

ABSTRACT

Aims: The Aim of this project is to design and construct a low cost laterite grinding machine that's fabricated out of locally sourced materials whilst ensuring a high performance efficiency.

Study design: Model of the Machine; Fabrication of Machine and Testing of Machine.

Place and Duration of Study: Engineering Materials Development Institute, Akure, Ondo State, Nigeria, between November, 2020 – July,2021

Methodology: This project was carried out in a Mechanical Engineering Workshop. The Machine was first modelled through the use of Autodesk Inventor modelling software, simulations of the running of the different parts of the machine was carried out to ensure a smooth alignment of the different moving parts of the machine before the whole fabrication process began. The major operations on the machine were welding, machining of parts (turning and facing operations) and the assembly was done under a well-controlled environment. 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. The grinded laterite is collected through a delivery chute below. The hammer mill operates at a speed of 2267 rpm transmitted by a pulley-belt drive from a 4.85kW diesel engine with a rated speed of 2600rpm.

Result: The 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. The estimate cost of the machine is 787,710.00 Nigerian naira. After performance evaluation of the machine was carried out, it worked with a 98.2 crushing and grinding efficiency

Keywords: Laterite, Grinding, Design, Hammer mill, Grains, Particles.

1.1 INTRODUCTION

Laterite is a highly weathered material, rich in secondary oxides of iron, aluminium, or both. Laterites are products of intensive and long lasting tropical rock weathering which is intensified by high rainfall and elevated temperatures. They are an important source of many metal ores, particularly nickel, cobalt, manganese, iron and aluminium [3].

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 [4]. 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 [5].

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 [1]. 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 [2]. 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. 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 [1].

1.2 METHODS OF CRUSHING LATERITE

There are various types of machines generally used for size reduction 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 [3]. 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 [6].

Crushing operation is becoming very popular in the Nigerian mineral industry, because of the growing awareness of the minerals deposits that abound in the country and the importance of these mineral resources in the economic development of the country [8]. The mining industry has been unable to meet up with the demand of this 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. 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. 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 [7].

1.3 AIM OF THE PROJECT

The main aim of this project is to develop an efficient hammer mill suitable for laterite grinding.

1.4 OBJECTIVES OF THE PROJECT

The objectives of this project are to:-

1. develop an efficient Laterite Grinder
2. carry out performance evaluation of the machine

1.5 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.

1.6 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 general design was based on the process of allowing a strong and durable metallic object in form of hammers to beat any material that obstruct its way during operation, thereby resulting into breakage of the material which can also be referred to as size reduction in comminution operation. 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 parameters 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.

1.7 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.

1.8 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.

1.8.1 BASIC DESIGN

Determination of Shaft Speed

To calculate the shaft speed the following parameters are used.

$$\frac{D_1}{D_2} = \frac{N_2}{N_1} \qquad (1)$$

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 only obtained when there is no slip condition of the belt over the pulley. When slip and creep condition is present, the value (913.5rpm) is reduced by 4% (Spolt, 1988).

Determination of Nominal Length of The Belt

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

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:

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

And Centre distance maximum:

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

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

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

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

Determination of the Belt Tension

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

$$T_2 = SA$$

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

Determination of The Torque & Power Transmitted for the Shaft

$$POWER = (T_1 - T_2)V$$

$$T_r = (T_1 - T_2)V \qquad (7)$$

Where,

T_r = Resultant Torque

T_1 & T_2 = Tension in the belt, N

R = Radius of bigger pulley, mm

Determination of Hammer Weight

$W_h = M_n g$

Material = Mild Steel

Density = 7.85g/cm3

$$Density = \frac{Mass}{Volume}\ (kg/m^3) \qquad (8)$$

Determination Maximum Power Transmissible (Kw)

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

$$P = \frac{0.45}{V^{0.09}}\left[\frac{19.62}{D_o} + 0.765 + 10^{-4}V^2\right]V \qquad (9)$$

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

Determination of Hammer Shaft Diameter

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

$$\frac{I}{Y_{max}} = Z = \sigma_s = \frac{M_b}{Z} \tag{10}$$

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;

$$V = \frac{h}{3}\left(A + a + \sqrt{Aa}\right) \tag{11}$$

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, $h = l\cos\phi$ 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=16.92x10^6mm
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 ≅ 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 = 7.16x$10^{-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;	d = 35mm

	Kb= 1.5; $K_t = 1.0$; $S_s = 55\times10^6\ N/m^2$	

2.0 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,
- Availability of the material locally and ease in obtaining them,
- Durability
- Economy / feasibility
- Cost of material and hence production cost with consumer in view,
- Ease of fabrication

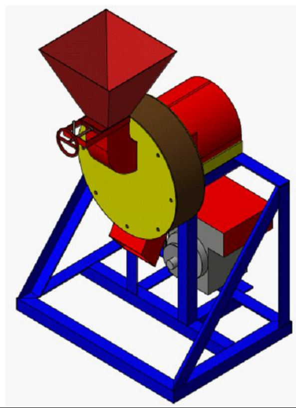
S/N	Machine Component	Criteria for Selection	Most Suitable Materials	Materials Selected	Reason for Selection
1.	Shaft	Strength, machine, surface finish, weight, cost, availability.	Mild steel, cast iron	Mild steel	High strength and light weight
2.	Pulley	Weight, good wearing property, availability	Mild 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, good wearing property, 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

Table 2: Materials Selection Procedure

Results and discussion

3.0 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.



3.1 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:

DESCRIPTION	DATA
Power	4.85 Kw
Speed	2600rpm

Table 3: Diesel Engine Specifications

Figure 2: 3D Model of the Hammer Mill

Figure 3: Picture of the Developed Hammer Mill

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;

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**

Table 4: Performance Evaluation of Machine

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;

$$GC = \frac{M}{t}$$
$$GC = \frac{147.3}{1.428}$$
$$GC = 103.15kg/hr \approx \mathbf{100kg/hr}$$

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;

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

Where; $GE = Grinding\ efficiency$

$average\ mass\ of\ crushed\ laterite = 147.3kg$

$average\ mass\ of\ laterite\ loaded = 150kg$

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

$$\mathbf{GE = 98.2\%}$$

4.3 CONCLUSION

The laterite grinder 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

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