FEDERAL UNIVERSITY OF TECHNOLOGY, AKURE
JOURNAL OF ENGINEERING AND ENGINEERING TECHNOLOGY

DEVELOPMENT OF AN ADJUSTABLE HOPPER FOR HAMMER MILL

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Olutomilola E. O., Otokola T. O. and Ajayi, V. A. (2024): Development of an Adjustable Hopper for Hammer Mill. *Journal of Engineering and Engineering Technology /18(1), 56-62*

Received Date: 10.11.23 **Accepted Date: 15.3.24**

Abstract
This paper presents the design, fabrication, and preliminary testing of an adjustable hopper. The design process involved sketching and modeling of the hopper using Solidworks computer-aided design (CAD) application software. The hopper design allows for the adjustment of the hopper's angle of repose, allowing for greater control over the flow rate of materials being milled. Stainless steel was selected for the hopper's fabrication because it was the material used for fabricating the hammer mill and is a food-grade material. A finite element analysis (FEA) was conducted to evaluate the hopper's structural integrity and durability. Prior to fabrication, the FEA results indicated that the hopper design was suitable for fabrication. A preliminary test was conducted on the hopper after fabrication, and it was discovered that making the hopper's angle of repose adjustable allows the operator to control the flow rate of materials being introduced into the milling chamber. This will help improve the overall efficiency of the hammer mill. More testing and monitoring are recommended to validate the hopper's long-term performance and economic benefits.

Keywords: *Adjustable hopper, development, flowrate control, hammer mill, simulation*

Introduction

Hammer mills are machines designed for pulverizing or grinding materials into smaller particles by repeatedly hitting them with rotating hammers (Adeyeri, 2016; Ezurike et al., 2018; Sanusi et al., 2022). Because of their capacity to grind various materials into desired particle sizes, they are commonly used in industries such as agriculture, food processing, and biomass processing (Bucham et al., 2022; Oyelami and Oluwole, 2023). Hammer mill is widely used for size reduction of dry solid materials due to its high throughput rates and capacity to pulverize different dry materials (Probst et al., 2013; Mugabi et al., 2019). Among other components, hammer mill consists of a hopper, which serves as the feed inlet and can also be used to control the feed-rate depending on its geometry. A hammer mill hopper is a container or receptacle used to hold the raw materials or feedstocks that are to be processed by a hammer mill. The hopper is usually designed in such a way that an operator cannot put his/her hand inside the milling chamber (Olutomilola 2019; Olutomilola et al., 2021). However, the hopper's design can significantly influence material's feed-rate, which in turn can influence the overall performance or efficiency of a hammer mill. Thus, a hopper serves the following important functions when used with a hammer mill:

(1). Material Storage: The primary function of the hopper is to store and provide a consistent supply of raw materials to the hammer mill. This ensures a continuous and efficient operation of the mill.
(2). Feeding Mechanism: Many hammer mills are equipped with mechanisms that control the rate at which material is fed into the grinding chamber. The hopper helps regulate and control this feeding process (i.e., it ensures a consistent and regulated flow of material for processing).
(3).Safety: Hoppers often come with safety features to prevent accidental contact with the hammer mill's moving parts. They may have covers or guards to protect operators from potential hazards.
(4.) Capacity: The size and capacity of the hopper can vary depending on the specific application and the desired throughput of the hammer mill. Larger hoppers are used for industrial-scale processing, while smaller hoppers may be suitable for smaller operations.
(5). Material Flow: The design of the hopper can influence how material flows into the grinding chamber, affecting the efficiency of the hammer mill. Proper hopper design can help ensure even and consistent feeding of materials. Thus a hopper can help to ensure that the materials enter into the grinding chamber at a consistent rate.

(6). Dust Control: In some applications, hoppers may also include dust collection systems to minimize the release of dust and airborne particles during the milling process.

The size and design of a hammer mill hopper can vary widely depending on the specific application and the type of material being processed. It may be a small hopper for a laboratory-scale hammer mill or a large, automated hopper for an industrial-scale production line. In a nutshell, the hopper is an integral part of the hammer mill system, ensuring the efficient and safe processing of materials. Although extensive studies have been done on hammer mill as a size reduction method for dry-solid materials, the development of a flexible or an adjustable hopper for the machine still remains a research gap that needs to be bridged in this study area. Hence, the aim of this study was to develop a hopper whose angle of repose could be varied from 0° to any desired angle to the horizontal. The study also sought to evaluate the effect of varying the hopper's angle of repose on hammer mill performance and efficiency.

Designing a hopper for a hammer mill involves several considerations, including the type of material to be processed, the size and capacity of the mill, and the space available for the hopper. These considerations ensure efficient operation and material handling. Hence, some key steps and factors to be considered when designing a hopper for the hammer mill are as follows:

(1). Material Characteristics: Understand the properties of the material to be processed. Consider factors such as particle size, density, moisture content, and abrasiveness. This information will influence the hopper design.

(2). Mill Specifications: Determine the specifications of your hammer mill, including its capacity, rotor size, and power requirements. The hopper design should complement the mill's capabilities.

(3). Hopper Shape and Size: Choose an appropriate hopper shape (e.g., conical, rectangular) based on your space constraints and material flow requirements. Calculate the hopper volume to ensure it can hold an adequate supply of material for uninterrupted operation.

(4).Material Flow: Design the hopper to promote a consistent and controlled flow of material into the hammer mill. Consider using features like sloped sides and vibration aids to prevent bridging and ensure a steady flow.

(5). Inlet Geometry: The hopper's inlet should match the hammer mill's inlet geometry to facilitate smooth material transfer. A well-designed transition between the hopper and mill inlet can reduce the risk of material blockages.

(6). Feed Mechanism: Determine the method of material introduction from the hopper into the hammer mill. This may involve gravity feeding, conveyor systems (belt or screw), or pneumatic systems. Choose the one that suits your specific application and material characteristics. Ensure that the inlet design allows for uniform distribution of material across the mill's rotor.

(7). Safety: Implement safety features to prevent accidental access to the hammer mill while it's in operation. Consider the need for dust collection and ventilation to maintain a safe working environment.

(8). Material Handling or Discharge: Select appropriate discharge mechanisms, such as chutes, conveyor belts, augers or other systems, to transport the processed material away from the hammer mill efficiently. Design the hopper and discharge system to minimize dust generation and spillage.

(9). Accessibility and Maintenance: Ensure that the hopper design allows for easy access and maintenance of both the mill and the hopper itself. Include inspection and cleanout ports if necessary.

(10). Structural Integrity: Design the hopper with the necessary structural support to handle the weight of the material and any dynamic forces generated during operation.

(11). Testing and Iteration: Prototype and test the hopper design to ensure it meets the desired performance criteria, including material flow, capacity, and safety. Be prepared to make adjustments and refinements based on actual performance.

(12). Compliance: There is need to check and comply with any relevant industry standards, safety regulations, and local codes when designing and installing the hopper.

It is to be noted that the specific design of the hopper depends on certain unique requirements and constraints, so it's important to work closely with engineers or experts experienced in material handling and process equipment design to ensure the success of the design, which this study did.

Materials and Methods

Stainless steel was selected for the hopper because it is the material that was used for fabricating the hammer mill.

Design Considerations for the Hopper

The following factors were taken into consideration for the hopper's design (Roberts, 2010; Lobato et al., 2016):

1. Flow pattern: Flow problems can be minimized by ensuring mass flow pattern exists which is achieved by ensuring that the converging walls of the hopper are steep enough and friction is low enough to allow bulk material slide along them.
2. Minimum outlet dimension: The outlet size must be large enough to prevent blockage. The outlet

size depends on the cohesive strength and bulk density of the material to be milled.

3. Flow rate: The hopper should be designed in such a way that the flow rate of the materials into the milling chamber must be controlled by adjusting sliding plate's angle of inclination. The flow rate is determined by the flow factor and flow function.

4. Geometric Constraint: This involves constraining all entities in the design before assembling in relation to their positions, characteristics, sizes, symmetry, the angle and distances. This was achieved on solidworks CAD application software.

5. Angle of Inclination or Repose: The Angle of repose (also called the angle of friction of rest) is the maximum slope at which a heap of any loose or fragmented bulk material will stand without sliding.

6. Discharge rate: The rate at which the materials from the hopper is being released into the milling chamber should be considered when designing the hopper. The maximum flow rate of powdery or fine material can be severely lower than that of coarse material.

The Hopper's Description

The hopper design followed a systematic approach as in defining the requirements such as, the angle of flow, the discharge rate, the materials required and properties of the materials. All the constraint were identified including the hopper's geometry. Model for the hopper was developed using solidworks CAD application software (see Figures 1 and 2). The adjustable hopper assembly consists of the hopper walls, adjustable rectangular tray, 16 volts power pack, 12 volts DC motor, a screw jack, a switch, housing for the DC motor and screw jack, and the housing supporting frame. The hopper walls serve as container and channel for incoming materials. The rectangular tray gives the operator the opportunity to change or vary the hopper's inclination angle. The power pack is a combination of the power cable and transformer of a laptop, which serves as an AC to DC converter. The DC motor helps to control the up and down motion of the screw jack, which is responsible for adjusting the angle of inclination of the adjustable rectangular tray. The switch is for OFF and ON of the DC motor. The frame is used to hold the box that houses the DC motor and screw jack to the required height. The frame also reduce the effect of vibration on the hopper. The hopper design allows for adjusting the angle of repose, thereby providing flexibility in controlling the flow rate of materials to be milled.

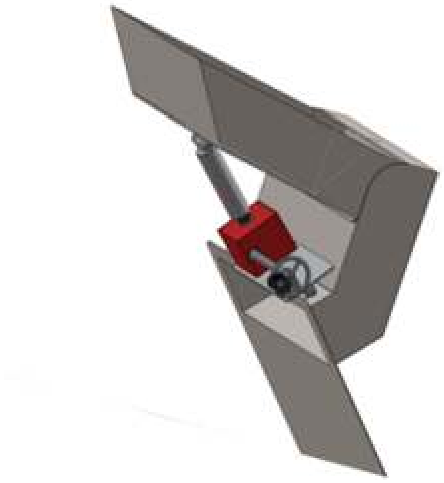

Figure 1. Developed model of the hopper

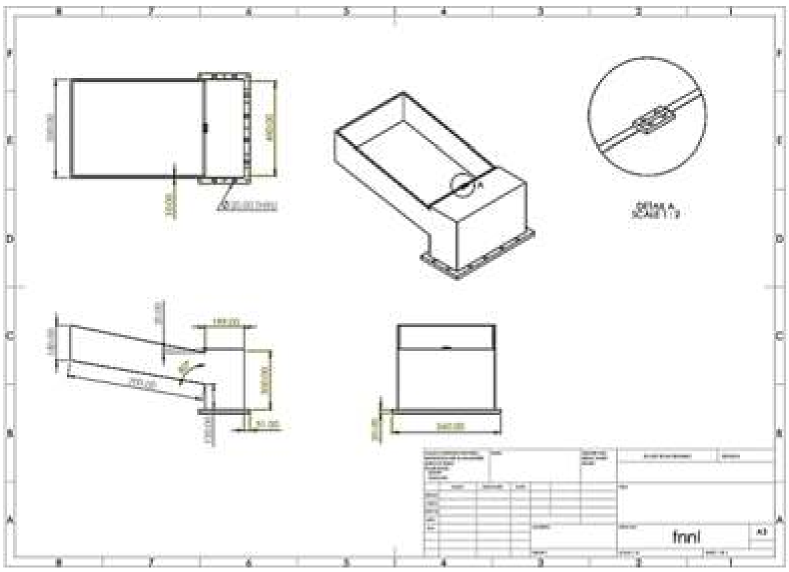

Figure 2. Orthographic and isometric views of the hopper

Design Analysis of the Hopper

The dimensions of the hopper were determine from the hammer mill's design parameters. The following parameters are calculated in order to analyze the hopper's design. The volume of material to be milled was calculated to be 2109.7 cm^3 using Equation (1); while Equation (2) was used to hopper's volume to be 465,500cm^3.

$$V_{fm} = \frac{m_{fm}}{\rho_{fm}} \quad (1)$$

$$V_{TH} = (L_{ah} \times B_{ah} \times H_{ah}) + (L_{fhp} \times B_{fhp} \times H_{fhp}) \quad (2)$$

Where: V_{fm}, m_{fm} and ρ_{fm} are the volume, mass and density of the material to be milled, respectively; V_{TH} is the hopper's volume; L_{ah}, B_{ah} and H_{ah} are the length, breadth and height of the adjustable part of the hopper, respectively; L_{fhp}, B_{fhp} and H_{fhp} are the length, breadth and height of the fixed part of the hopper, respectively.

Simulation of the Hopper

Simulation was done on the developed model during which anticipated loads were applied to test the suitability of the model for fabrication. Finite Element Analysis (FEA) was conducted to assess the hopper's structural integrity and durability. Assumptions were made where necessary to supplement the analysis. A force of 150N was applied on the assembled hopper as shown in Figure 3

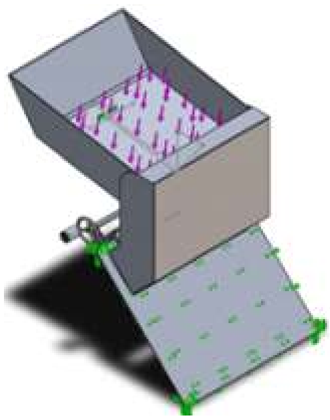

Figure 3. Load applied normal to the base.

Fabrication of the Hopper

The fabrication process of a hopper involves several crucial steps to ensure the hopper is built according to the desired function. The fabrication began with procurement of materials and other component parts of the hopper assembly. This was followed by marking-out, cutting, shaping, joining and assembling of the hopper. The individual components were assembled by welding and fastening with bolts and nuts. During the assembly process, proper alignment was ensured to maintain the structural integrity of the hopper. Surface treatments were applied to the fabricated hopper to provide protection against corrosion, improve aesthetics, and enhance performance. This process involves cleaning, grinding, sand papering and application of paint as protective coatings. An opening was then created beneath the hopper, through which the material to be milled enters the milling chamber of the hammer mill. A thorough inspection was conducted to ensure that the hopper meets the design specifications and quality standards. The fabricated hopper is shown in Figures 4 and 5.

Figure 4. The fabricated hopper

Figure 5. The hopper after installation

The Hopper's Mechanism

The adjustable part of the hopper is made so by attaching its end to the neck of the hopper with the aid of two hinges. The hopper makes use of a screw jack in moving the adjustable part in upwards and downward motion. The screw jack is connected to the base of the adjustable part of the hopper and is controlled by the electric motor of 12volts which converts electrical energy flowing from the power cable into mechanical energy for lifting the part. The power pack has a transformer of 16volts that converts alternating current that is coming from the adapter into direct current that flows into the DC motor. The adapter on the other hand is plugged into the power source which supplies the energy required by the system. A switch is integrated into the system for directing the movement of the hopper.

Preliminary Testing of the Hopper

Preliminary testing of the hopper is a crucial step in assessing its efficiency, reliability, and functionality; and to ensure that the hopper meets the desired requirements and performs optimally in its intended application. The following tests were carried out on the hopper to access its performance:

1. **Adjustability Test:** The hopper was originally designed such that its angle of inclination could be varied from 0° to 90°. The hopper was tested by varying its angle of inclination to the horizontal from angle 0° to angles 28°. The variation could not go beyond 28° because the hammer mill to which the hopper is attached is a part of a process plant which could not allow the inclination angle to exceed 28° due to the height constraint brought about by the outlet chute of the feeding machine.
2. **Angle Accuracy Test:** The angle of repose of the hopper was varied and the angle shown on the hopper's protractor was compared with the one shown on a digital spirit level. This was done to ensure that the angle of inclination is accurate in order to prevent avoidable errors.

Results and Discussion

Simulation

The results of the stress analysis is presented in Figures 6 to 8. It can be seen that the stress induced in the hopper ranged from a minimum value of 0 N/m² to a maximum of 7.896×10^{4} N/m². The maximum stress induced in the hopper (7.896×10^{4} N/m²) is observed to be far lower than the yield strength of the material used (stainless steel) which is 2.757×10^{7} N/m² (Figure 6). The static deformation result is shown in Figure 7. Here, it is noticed that the displacement caused by the applied force on the hopper ranged from 1.0×10^{-30} mm² to a maximum value of 5.585×10^{-4}mm². The maximum deformation (5.585×10^{-4}mm²) after the loads applied is seen to be insignificant when compared to a real life model. The static strain on the hopper (Figure 8) is also shown to be insignificant to the material (stainless steel). The strain simulated ranged from a minimum value of 0 mm to a maximum value of 7.364×10^{-7}mm.

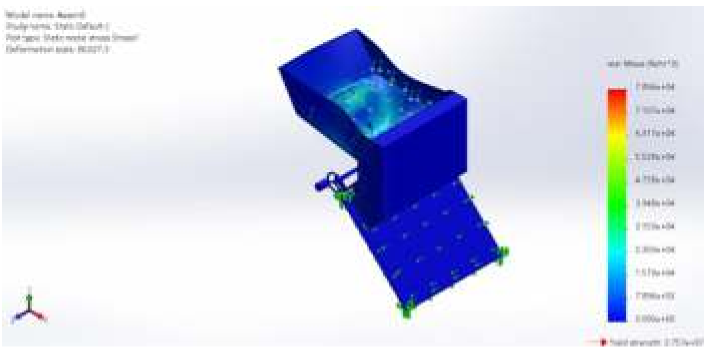

Figure 6. Static stress result

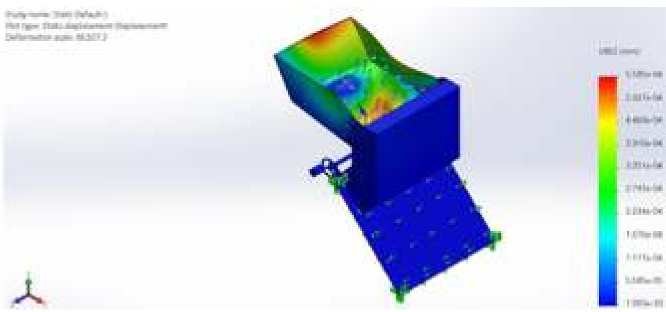

Figure 7. Static deformation result

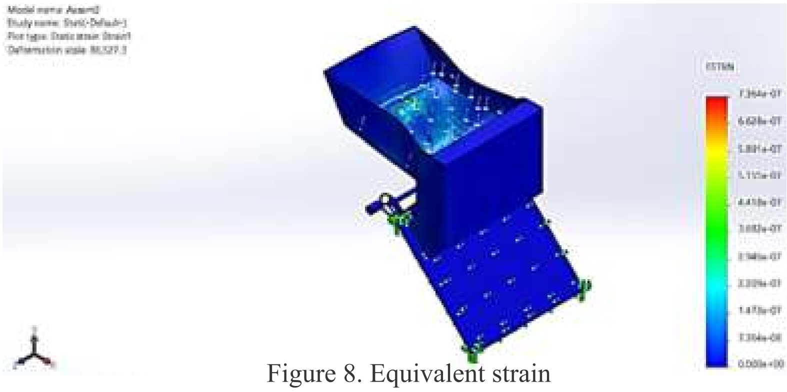

Figure 8. Equivalent strain

Preliminary

The machine was tested and it was noticed that the hopper could be adjusted to a maximum of 28° to the base of the adjustable part of the hopper. From the result shown in Table 1 and Figure 9, it can be seen that the angle shown on the hopper's protractor corresponds with that of the digital spirit level. Also, placing the DC motor and screw jack on a frame reduced the effect of vibration on the hopper.

Table 1: Hopper' inclination angles on protractor versus digital spirit level

S/N	Hopper Protractor (?)	Digital Spirit Level (?)
1	0	0
2	1	1
3	2	2
4	3	3
5	4	4
6	5	5
7	6	6
8	7	7
9	8	8
10	9	9
11	10	10
12	11	11
13	12	12
14	13	13
15	14	14
16	15	15
17	16	16
18	17	17
19	18	18
20	19	19
21	20	20
22	21	21
23	22	22
24	23	23
25	24	24
26	25	25
27	26	26
28	27	27
29	28	28

Figure 9. Accuracy test of the hopper visualized

Results and Discussion

From the simulation and functional test results, it was affirmed that the hopper was fit to replace the old hopper. The simulation results shows that the hopper is able to withstand a load of 150N without causing significant strain within the hopper. From the performance testing, it was discovered that the hopper provides for easy experimentation. The angle of inclination of the hopper can be adjusted to fit the angle of repose of any food materials. This makes it a kind of universal hopper for hammer mill.

Conclusion

The hammer mill fitted with an adjustable hopper has demonstrated improved performance in terms of flow rate control, efficiency, and durability. The adjustable angle of repose allows for precise control over the material flow, thereby optimizing the milling process. The FEA results indicate that the hopper design is structurally sound and capable of withstanding operational demands.

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