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The Development and Fabrication of a Stone crusher

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Abstract
A crusher is a machine that uses a metal surface to break or compress materials into finer, denser pieces. It is one of the main devices used for size reduction in metallurgy, machinery, and other similar industries. They are available in a variety of sizes and capacities, starting at 30 tons per hour. They can be classified according to the degree of decomposition of the raw materials and the method of application. There are three types of breakers depending on the mechanism used: namely cone crusher, jaw crusher, and impact crusher. The main objective is to design an impact stone crusher incorporated with a grinder. Impact stone crusher involves the use of impact rather than pressure to crush materials while the grinder works based on the abrasion principle, The most common crushing machines are plastic crushers, jaw crushers, cone crushers, stone crushers, and so on which crush engineering materials to maintain space and easy transport.

Keywords: *Crusher, Metal, break. Compress, Materials Size, Denser, Impact, Stone, Machine, Decomposition, Grinder.*

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I. Introduction

Cusher is one of the main devices used for size reduction in metallurgy, machinery, and other similar industries. (Balasubramanian, 2017). Available in a variety of sizes and capacities, starting at 30 tons per hour, Up to 1000 tons per hour. They can be classified according to the degree of decomposition of the raw materials and the method of application. For the stone crusher component of the machine, Stone crushing is one such industry that exists in almost every major city/town in every state as construction activities take place all over the country. Transporting stone over long distances increases the price of crushed stone products, which is why the incorporation of a grinder into an existing stone crusher is a unique innovation of this research work. Crushers must be used in cities in the construction of bridges, canals, etc (Kumar, 2016). It must be located near an application center. Operating a stone crusher requires electricity and a lot of manpower. Driveways are also required for transporting quarry products and gravel. For this reason, most stone crushers are located on the outskirts of cities or near large construction sites. In most cases, Stonebreakers are found in groups of 5 to 50 units per cluster. Crushers are located closer to sources of raw materials, such as stone mines and riverbeds. curved stone crushing methods such as hammers and anvils are employed due to a lack of capital to purchase highly mechanized, efficient, and expensive stone crushers. These remote methods are labor intensive, low productivity, unhealthy, low quality, and generally cause large differences in scale.

The most common crushing machines are plastic crushers, jaw crushers, cone crushers, stone crushers, and so on which crush engineering materials to maintain space and easy transport. Also, the crusher is typically graded based on the hardness of the material, Sathish Paulraj Gundupalli et.al (2016). A stone crusher incorporated with a grinder has been developed to reduce the effort required to produce aggregates and protect the environment as well as save the time expended in converting crushed stones into the grinder. The device is made from locally available materials. This will help reduce overall production costs, increase local expertise, reduce dependence on imports, and boost the economy. (Campbell et al., 2011). Total production may not be able to meet Nigeria's high demand with currently available machines. Rough stone crushing is widely used in various operations in the country. This is a tiring, inefficient, and time-consuming activity (Egbe et al., 2016). The use of crude tools for breaking stones is common among the various native peoples of the country. This often leads to clearing by burning firewood to aid the manual chipping process as it causes microscopic cracks in the rock. (Obojes et al., 2006). Interestingly, the shredders available in research institutes and universities in the country are imported and very expensive (Egbe, et al., 2016). Solids recovery machines are often classified as shredders (Richard, 2002).Currently, the stone-crushing industry in Nigeria is experiencing a growth trend with large public and private sector investments in construction, real estate, and infrastructure development. However, most people in this field cannot afford to purchase machinery to produce bulk filler. This research work is targeted to overcome the stress and energy expended while compressing or crushing stones into smaller sizes and for easy movement and easy recycling.

II. Materials and Methods

This research paper is focused on the designed to crush stones into smaller sizes and then into granulated form. it is designed to also reduce their volumes but the design concept does not take into consideration of crushing materials other than stone. A comprehensive feasibility study and the processes involved in the design and the assembled procedures involved.

2.1 Design Analysis Of Machine Parts

Design Analysis and Calculations Crushing may be achieved using either applying a compressive or impact force on a solid particle. The Equation below is used for estimating the crushing energy required to reduce the size of a solid particle that is coarse. It is often referred to as Kick's law

E = KkIn …………………………………….. (1)

where kK is the Kick's coefficient, xf, and xp are feed and product sizes respectively in mm.

Design Considerations: Some basic specification is provided herewith; 400 kg/h is the target capacity for the machine and must be dust-tight to reduce the propagation of dust produced due to the crushing process. **Determination of the Energy Requirement of the feed size and product size specifications**: For this work, 50 mm and 10 mm respectively, and granite is the material to be used for performance evaluation. The average work index of granite is 16.6 kWh/and its compressive strength is 200 MN/m2. The energy required to crush coarse particles is provided by a modified Kick's equation.

$E = k k C s l n (x f / x p)$ …………………………………. (2)

Where:

P = Power needed to crush the stone in Watt

ṁ = the feed rate in kg/s,

$k k$ = the Kick's coefficient,

$C s$ = the compression strength of the material in MPa

$x f$ and $x p$ = inlet feed and outlet product sizes in mm respectively.

P = 1.72 kW, and subsequently the energy as 4.3 kJ, the design power is obtained by considering a service factor.

Design power (PD) = $S f \times P$ ………………………………………… (3)

Where:

Sf = Service factor

P = Required power in W.

Gasoline engines rarely provide a 100 % efficiency rating in selecting one, the efficiency must be considered. Gasoline engines in the power range of 1 to 6.5 hp have an efficiency of 0.84. This is adequate as PD was obtained as 3.4 kW. The values were slotted into equation (4).

ηm = PD/Pin .... (4)

Thus; Power input =4847.04917 W or 6.5 hp. The nearest higher power and available gasoline engine of 6.5 hp was selected for the machine.

Determination of Hammer Plate Dimensions: The maximum shear stress required to crush granite will be half its compressive strength, (that is 100 MPa) by applying the maximum shear stress theory of failure. The maximum area resisting crushing of a 50 mm diameter stone is its cross-sectional area, πr^2 . The stress acting on the stone is given by.

Crushing Stress $(\sigma)\ c r u s \square i n g = F 1/A$ .... (5)

Where:

Crushing stress (σ) = crushing stress in MPa

Resisting Force (F1) = Force resisting crushing in N

Area =A is the area in m^2.

Resisting stress is then obtained as

F1 = $100 \times 10\ 6 \times \pi\ 0.025$ = 196.35 KN

If the hammer plate is not to shear relative to the stone, then its material resistance to tear (F2) must be greater than F1. Adopting available SAE 1010 (cold drawn) steel and the same maximum shear stress theory, a shear strength of 150 MPa was obtained. The load on the hammer plate varies from zero to a maximum impact load.

Thus, a factor of 1.5 was used to account for the fatigue effect and ensure that the material resistance of the plate (F2) is greater than F1.

This implies that,

F2 = $150\ 1.5 \times 10\ 6 \times b \times t \geq F 1$ ………………………………. (6)

where b and t are the width and plate thickness respectively. Since there is only one equation, a width dimension of 100 mm was adopted .
The required thickness was determined as
150 1.5 × 10 6 × 0.1 × t = 196,350
Then, the thickness is obtained as
T= 19.64 mm,
Which is approximately 20 mm.

1. Belt Selection and Analysis

CROSS SECTION	LOAD OF DRIVE (KW)	RECOMMENDED MIN. PULLY PITCH DIAMETER (D) (MM)	NOMINAL TOP WIDTH DIAMETER (B) (MM)	NOMINAL THICKNESS (T) (MM)
A	0.75 – 5	75	13	8
B	2 – 15	125	17	11
C	7.5- 75	200	22	14
D	22 – 50	355	32	19
E	30 – 190	500	38	22

A belt drive is used in this design as it simplifies the design of the machine and reduces the cost. The Table above is used to select a belt type, considering the power determined.

Table 1: V-Belt Power Ranges.
Cross section
Load of drive (kW)
Recommended min. pulley pitch diam., d (mm)
Nominal top width, b (mm)
Nominal thickness, t (mm)
The twisting moment in Nm for belt drives is given by
$T s = (T 1 - T 2)$ ……………………………….. (7)
where T1 and T2 are tensions on the tight and slack side in N and R is the pulley radius in m.
The maximum belt tension is obtained from is given as.
$T = \sigma b t$ ……………………………………………….. (8)
The allowable safe stress σ is 2.1 MN/m^2 as recommended, where b and t are the belt thickness and width are 17 mm and 11 mm respectively as seen in Table 1 above.
T1 = 357.66 N, in
the tension in the tight side.
while tension in the slack side is obtained as;
$T 1 / T 2 = e \mu \theta 1 c o s e c \beta$ ………………………………………………………. (9)
where μ is the coefficient of friction,
ϴ is the contact angle on the small pulley
β is half the angle of V pulley.
Substituting and solving yields tension on the slack side of the belt
T2 = 22.13 N.
The large pulley radius of 0.095 m is selected for the machine. Thus, the belt twisting moment is obtained as
Ts = 31.08 Nm.
Number of Belts Required Power transmitted by the hammer mill shaft
This is given by the equation below.
$P = \omega Ts = 2\pi N / 60\ Ts$ …………………………………………….. (10)
Where:
N is the speed of the shaft in revolutions per minute (rpm).
Power (P) = 4.2 kW.
The power input obtained was 4.1 kW which is lower than the power transmitted by the shaft which is 4.2 kW; therefore, one belt is required to transmit power for the crushing.

2. Belt Length Consideration:

Belt length is obtained using the equation:
LB = π/ 2 (D1 + D2) + 2C + (D1−D2/ 4C)^2 ………………………………. (11)
D1 and D2 = Pulley diameters adopted as 0.19 m and 0.14 m respectively.
C = the distance between the pulleys and is 0.41 m.
Therefore, LB = 1.34 m = 1340 mm So, the belt type B with a length of 1346 mm is selected for the machine.

Determination of Shaft Diameter According to the American Society of Mechanical Engineers:
ASME design code for solid shaft with combined torsion and bending load is given by;
$d^3 = 16 / \pi S s \sqrt{(M k b)^2 + (T k t)^2}$,,, (12)
where Ss is the allowable shear stress for steel with keyway as 40 MN/m^2,
Kb = bending factor = (due to high level of shock and fatigue),
Kt = torsion factor = (due to high level of shock).
T = torque and has been obtained as 31.08 Nm
M = the maximum bending moment.
To obtain the resultants for the vertical forces
RBV and RFV at points B and F the sum of upward and downward forces is equated, then the moment about A is taken, $\sum M A = 0$. ……………………………………… (13)

Design Analysis of Stone Crusher and Stone Grinding Machine
Crusher throughput calculation
i. Capacity: The capacity or throughput required in tons per hour or cubic meters per hour was determined. The capacity considered is 100 tonnes.
ii. Feed Size: we considered the maximum size of the stones to be fed into the crusher. The maximum stone size is 200mm.
iii. Reduction Ratio: to calculate the reduction ratio, which is the ratio of the feed size to the product size.
Reduction ratio = feed size / Product size …………………………. (14)
20:1 Ratio was considered for a finer product
(a) To calculate the product size
Product size = feed size/reduction ratio …………………………. (15)
= 200/20
Product size = 10mm
Crusher Efficiency: we evaluated the efficiency of the crusher in terms of energy utilization and product quality.
(b) Energy consumption calculation:
1. Power Consumption: To calculate the power consumption of the stone crusher or grinding machine. This involves considering the Motor Power, Efficiency, and other factors.
Power = Force x Distance x Time………………………………………. (16)
The Motor Efficiency is 90% and the Crusher operates for 8hrs
The force is 500N
Distant = 2m
Time =8hrs
Power = 500 x 2 x 10 = **10000watts**
1. **Energy Efficiency:** The overall efficiency of the machine was assessed.
1. Grinding machine calculations:
1. **Grinding Ratio:** In the case of stone grinding machines, we were interested in the grinding ratio, which is the ratio of the materials removed to the volume of grinding wheel wear.
Grinding ratio = materials removed / wheel wear …………………. (17)
20mm of materials are removed and the grinding wheel wears down by 5mm, the grinding ratio is
20mm / 5mm = 4mm
Therefore, the grinding ratio is 4mm
2. **Surface Finish:** The surface finish was evaluated after achieving the grinding process. The grinding process achieves a surface finish of 0.2 cubic centimeters.

Wear and maintenance calculations:
1. **Linear Wear in Crushers:** The wear rate of liners in the crusher was calculated as it affects maintenance schedules.
Wear rate = change in linear thickness/operating hours …………………………… (18)
The initial linear thickness is 100mm and after 500hrs of operation it has worn down to 80mm
Wear rate = (100 – 80) / 500 = 0.04mm/hr
2. **Grinding Wheel Wear:** The wear rate of the grinding wheel in the stone grinding machine was assessed.
Operating parameters:
Rotational speed (RPM): 500
Power: 10kw
Torque is calculated based on power and speed
T = P/2π * RPM / 60 ……………………………………. (19)
Torque = 1.59155 * 8.3333
= **13.2628 NM**

Applied loads
Crushing force(F) = 20KN (force exerted by the hammer during crushing)
Material properties:
The shaft material is alloy steel
Safety factor:
1. Safety factor for material 1.5
2. Safety factor for loading condition 1.2

Bending Moment
The two shafts' diameters are 25mm and 30mm
M = F * Diameter …………………………………. (20)
(1) At 25mm diameter :
M = 20KN * 25mm
M = 500KNmm
(2) At 30 mm diameter:
M = 20KN * 30mm
M = 600KNmm
3. To get the Diameter of the shaft that connects to the hammer crusher:

Hammer crusher diameter $= \sqrt[3]{\frac{16*600000*1.2}{\pi * 600mm * 1.5}}$ = **15.97mm**

2.3 COMPONENTS OF STONE GRINDER

A stone grinder, often used for grinding grains or other materials, consists of various components, and each part serves a specific function:

1. **Grinding Stone Wheel:** The grinding stone, often made of natural stone or synthetic materials like corundum or silicon carbide, is the central component that rotates and grinds the material. It's responsible for breaking down the substance being processed into smaller particles.

Plate 2.1: Grinding stone wheel

2. **Base or Housing:** The base or housing provides support and stability for the grinding stone. It can be made of wood, metal, or plastic and keeps the grinder securely in place during operation.
3. **Hopper or Feed Tray:** The hopper or feed tray is where you place the material you want to grind. It guides the material onto the grinding stone and ensures a controlled feed rate.
4. **Adjustment Mechanism**: The adjustment mechanism allows you to control the fineness or coarseness of the grind. This can be achieved by changing the distance between the grinding stone and the base.
5. **Retaining Ring or Lock Nut:** This part secures the grinding stone in place and ensures that it remains firmly attached to the grinder's axle.
6. **Axle or Shaft:** The axle or shaft is connected to the grinding stone and allows it to rotate when the grinder is in use.
7. **Bearings:** Bearings are used to reduce friction and allow the grinding stone to rotate smoothly. They are typically located around the axle where it connects to the grinding stone.

Plate 2.2: Pillow bearing

8. **Support Brackets:** The support brackets help hold the grinding stone in place and distribute the force evenly.
9. **Mounting Plate or Clamps:** These are used to secure the grinder to a countertop or work surface, preventing it from moving during use.

1. COMPONENTS OF CRUSHER

Rotor: It consists of three 5mm plates bored 21mm diameter at the four corners,30mm diameter at the centers to hold the shafts, four 19mm shafts with 8inches length. The rotor is a rotating component that carries the hammers. It transmits kinetic energy to the hammers for the crushing process.
Hammers: The hammers are made from 5mm thickness mild steel to ensure efficient impact. The hammers have dimensions 160 mm x 60 mm with a 21mm hole bored 1m away from one end to allow the passage of the shaft.
Crushing Chamber: The design of the crushing chamber is essential for maximizing the impact of the hammers on the material. It considers factors like geometry, size, and shape to optimize crushing efficiency. Adequate space is provided for the crushed material to exit, preventing clogging and ensuring a continuous crushing process.
Casing: The casing encloses and protects the internal components of the crusher. It provides structural support and contains the crushed material during the crushing process.
Drive System: The drive system, often uses belts to transfer power from the gasoline engine to the rotor, enabling the rotation necessary for crushing.
Gasoline engine: The motor provides the power needed for the crusher to operate. It drives the rotor through the drive system.
Pillow Bearing: Bearings support the rotor's rotation. They are crucial for reducing friction and ensuring the smooth operation of the crusher.
Safety Guards: Safety guards protect operators from moving parts and potential hazards. They enhance overall safety during the crusher's operation.
Dust Control System: The dust control system minimizes airborne particles generated during the crushing process, addressing environmental and health concerns.
Feed Opening/Funnel: The feed opening is the point where materials are introduced into the crusher. It facilitates the entry of stones for the crushing process.
Base and Frame: The base and frame provide the structural foundation for the crusher. They offer stability and support, minimizing vibrations during operation.
The diagram in plate 3,2 below shows the fabricated stone crusher

Plate 2.3: Stone-crushing machine

III. RESULTS AND DISCUSSIONS

3.1 RESULTS

The correct starting sequence was followed in other to prevent damage to the machine. The materials were gradually fed into the crusher. Overloading was avoided in other to prevent damage and improve optimum efficiency. The crusher performance was regularly monitored and was tracked with monitoring devices. Adjustments were made to the crusher settings to achieve the desired product size. The conveyor belt was monitored and adjusted for continuous material flow. The dust level was monitored and controlled. Proper shutdown procedures were followed after operating.

It was ensured that the stone grinding machine was properly set up and secured. All safety guards and interlocks were checked. Pre-start inspection was conducted. The stone grinding machine was switched on. The machine was allowed to reach its operating speed before the introduction of the materials. The materials were gradually fed into the stone grinding machine. The feed rate was monitored in other to prevent overloading. The grinding process was regularly monitored including the particle size, temperature, and machine vibrations. The machine settings were adjusted in other to achieve the desired particle size. The dust collection system was activated in other to collect dust particles. The machine was shut down properly, the machine was secured and the power sources were isolated.

1. Performance and Evaluation of Machine

The type of stone used for the performance evaluation is granite with a recommended abrasion index of 0.388 suitable for hammer Crushers due to its availability and high usage for aggregates. Five tests were carried out in total with each initial feed weighing 3 kg per sample. Two separate tests were conducted; the crushing capacity of the machine and the product size distribution.

i. **Crushing capacity:** Before loading each stone was ascertained to have a 50 mm average diameter using a 50 mm sieve, and weighed to give 3 kg before pouring into the hopper (for five (5) test runs). After the desired size is achieved the product is collected through the outlet. The crushing time and the weight after crushing were recorded.

The Percentage material recovered after crushing Re (in %) and percentage loss can be obtained from a modified equation.

Re = material mass output/material mass input × 100

Percentage loss = mass input – mass output/mass input × 100

The machine efficiency is given as the ratio of the actual capacity obtained and the capacity the machine was designed

$Me = Actualcapacity/\ Designcapacity \times 100$

ii. Product size distribution analysis:

The product samples each were sieved individually, the sieves used are of 10 mm, 6.30 mm, 3.35 mm, and 2.0 mm sizes. Stones retained on the sieves were then used for analysis. The particle size distribution is expressed as a percentage retained by mass on each of the sieve sizes used.

$\% MRi = MRix/00\ TM$

Where:

MRi is individual mass retained in kg

TM is the total mass in kg.

The cumulative percent passing of the aggregate is found by subtracting the percent retained from 100 %

$Cumm\ \%i = 100 - \%\ Cummretained$i

Where:

$Cumm\ \%i$ is the Cumulative percent passing for each sample (kg)

$\%Cummretainedi$ is the percentage cumulative retained for each sample in kg.

The crushing capacity (CRC) is the mass of material crushed in kg/h and is determined according to.

$C = Averagemassaftercrush\ ing \times Time$ (secs) $Averagetimetakentocrush$

$Crc = 2.9 \times 3600\ 35.2$

Crushing Capacity, Crc = 301.53 kg/h

The theoretical through-put efficiency ε of the machine is determined from Equation.

$\varepsilon = Actualcapacity/Designcapacity$

$\varepsilon = 301.53\ /400 = 0.754$

Table 4.1 shows the results of the crushing operation of the machine.

Table 2.1: Output of the crushing operation of the machine

TEST SAMPLES	MASS BEFORE CRUSHING (kg)	MASS AFTER CRUSHING (kg)	TIME TAKEN (S)	MATERIALS RECOVERED (%)
1	5.00	2.91	30.34	96.27
2	5.00	2.98	39.37	96.76
3	5.00	2.91	37.38	98.76
4	5.00	2.91	36.19	98.76
5	5.00	2.98	34.69	97.20
6	5.00	2.95	36.19	98.20

The results of the crushing test are presented in Table. It can be seen that it takes a minimum time (30.34 s) to crush the materials with a 96.27 % recovery rate and the average mass of stone crushed by the machine is obtained as 2.95 kg while the average time taken is 36.19 s. The machine recovery rate is consistent considering the results obtained in Table 2. Only an average of about 2.8 % is lost during the test runs. This might be a result of debris during crushing and pulverized rocks being retained in the machine. The theoretical through-put efficiency ε of the machine is determined as 75.4% from Equation. The results obtained are favorable compared to those obtained by. Performance evaluation carried out on H2 commercial Hammer Crusher which had similar features to the fabricated stone crusher was able to achieve a capacity of 260 kg/h crushing gold ore.

IV. DISCUSSION

Stone Crusher Machine

1. Performance and Throughput: This is the crusher's ability to process materials efficiently and meet the desired throughput.
2. Product Quality: the quality of the product was evaluated including the particle size and shape. The crusher was able to produce the desired product characteristics.
3. Energy Efficiency: The energy consumption of the crusher was taken into consideration and some measures were taken to improve the energy efficiency. Calculations were done for the specific energy consumption with benchmark comparisons.
4. Maintenance and Downtime: Some maintenance practices were also adopted both planned and unplanned maintenance were considered.
5. Environmental Impact: Measures were taken to minimize environmental impact and regulate dust.
6. Safety Measures: Some safety measures were implemented during the crusher operation and effective safety protocols were adhered to.
7. Grinding Efficiency: The grinding efficiency was also considered in other to achieve the desired particle size. Data on grinding ratios, materials removal rates, and comparison with expected values were also noted.
8. Product Quality: The grinding machine meets the desired product specifications and the quality of the ground products was evaluated in terms of particle size distribution and surface finish.
9. Energy Consumption: The energy consumption of the grinding process was considered which includes specific energy consumption values and comparisons with energy-efficient particles.
10. Maintenance and Wear: The maintenance of the grinding wheel was also considered and maintenance procedures to improve the lifespan of the machine were put in place.
11. Dust Collection Control System: A dust collection system was also put in place in other to reduce airborne particles.
12. **Safety:** Safety procedures were also put in place during the operation of the stone grinding machine.

V. CONCLUSION AND RECOMMENDATIONS

5.1 CONCLUSION

An adaptive design concept for a Stone crusher and stone grinding machine designed and fabricated has been tested, and its performance evaluation results show that it has been able to meet its intended purpose in terms of efficiency.

5.2 RECOMMENDATIONS:

The following suggestions were given in light of individual experience with this novel work.
i. Smart technologies for monitoring and control can be integrated into the project to further elevate the project's appeal, making it adaptable to modern industrial standards.
ii. A well-documented user manual and training materials should accompany the final product to facilitate seamless adoption and operation by end users.
iii. Incorporating modularity in the design can facilitate maintenance and potential future upgrading.

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APPENDICES

Plate 3.1: Grinding machine shaft

Plate 3.2: Grinding stone wheel

Plate 3.3: Pillow bearing

Plate 3.4: Stone-crushing machine