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(RESEARCH ARTICLE)

Design of a breaking machine for separating pairs of high chromium grinding ball media

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Abstract

A high chromium grinding ball media coded NF6357A is a replacement casting produced by Nigerian Foundries limited, Lagos, Nigeria for cement mill grinding. The 30 mm diameter ball casting is produced by machine moulding. The balls come out in pairs after shakeout, and must be separated and heat-treated before delivery to the customers. In this study, a separating machine is designed to break the adjoining area of the pairs into a unit to overcome the challenges of the existing manual breaking. The machine composed of electric motor with reducer gear, chute/chute support, hammer and pulley. The ball pairs are manually fed into the chute and move by gravity for breaking by impact force of the hammer. The hammer is bolted firmly on the rotating pulley to hit the balls against the chute edge. Each separated unit of the ball falls off for collection and subsequent grinding/finishing operations. The breaker is designed to separate twenty (20) pairs of balls in about 7 minutes with shearing stress of about 450 N/mm^2 and capable of producing 4.5 KN impact force. This breaking shear stress is sufficient enough to overcome the shear strength of the grinding media which is about 379 N/mm^2.

Keywords: High chromium; Grinding media; Gating; Moulding; Shear stress

1. Introduction

A grinding ball is generally used in mining industries for grinding raw materials, such as coal, iron ore, quartz, etc., [1]. However, high chromium steel is one of materials that is commonly used as grinding ball, because of its high hardness and wear resistance, especially after undergoing heat treatment [2]. There are four types chrome grinding steel balls, namely; low chrome alloy grinding steel ball, middle chrome alloy grinding steel ball, high chrome alloy grinding steel ball and supper high chrome alloy grinding balls.

Grinding ball that was made from high chromium steel can be produced by sand mould-gravity casting and machine moulding methods [3]. However, a case study of diameter 30 mm high chromium ball grinding media is one of the range of products produced by Nigerian Foundries Limited for most cement industries in Nigeria. It is an outlay of steel with the following composition 1.4% C, 0.6% Si, 0.5% Mn, 0.05% P, 0.05% S and 150 %Cr. This product is designated as NF6357A.

The NF6357A ball has high abrasion/wear resistance and toughness to withstand low medium level impact with average hardness of 36 HRC [4]. The ball is produced by machine moulding, with two piece of cope and drag pattern.

After pouring operation, and subsequent solidification, the mould is taken to the shake-out section after cooling, where the balls are removed from the box, the ball would be seen to come out in pairs. These pairs must be separated into one ball for any useful application. For a long time in Nigerian Foundries Limited, Lagos, a well sharpened cutlass was being used to manually break a pair of the ball into two pieces.

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There were reported cases of accidents, waste of time and energy as a result of manual labour involved in separating the balls using this crude method. These shortcomings prompted the idea of locally designing and fabricating a semi-automatic and cost effective means of breaking the balls into two with minimum labour requirements. The ball breaker, when constructed would be fed manually while the breaking action would be automatic by shearing effect to eliminate numerous problems being encountered in the manual breaking method.

2. Material and methods

A grinding ball is generally used in mining industries for grinding raw materials, such as coal, iron ore, quartz, etc., [1]. However, high chromium steel is one of materials that is commonly used as grinding ball, because of its high hardness and wear resistance, especially after undergoing heat treatment [2]. There are four types chrome grinding steel balls, namely; low chrome alloy grinding steel ball, middle chrome alloy grinding steel ball, high chrome alloy grinding steel ball and supper high chrome alloy grinding balls.

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Figure 1 Machine moulding and pairs of grinding media balls

2.1. Material selection for development of breaking machine

The breaker consists of the following features: electric motor, gear box, pulley, chute, hammer/crusher, stands, base plate and holders. For adequate compressive and shear strength, mild steel of proper thickness was selected to fabricate the components parts. Necessary assumptions on the power rating and speed ratio were considered in selecting the type of the electric motor and the speed reduction gear used in the design.

2.1.1. Selection of electric motor

When selecting the electric motor, allowance was given to power loss in the driving unit. The speed of the electric motor was 1385 rev/mins. The motor was carefully selected taken into consideration power requirement, available gear box and space.

2.1.2. Selection of gear box

The gear box has a shaft diameter of 30 mm. when coupled with the electric motor, the speed ratio was 1: 46. Bringing the gear box speed to 30 rev/mins. The speed gave enough impact force required for the shearing action. Though series of trials were made before arriving at this acceptable speed ratio. Gear box of shaft diameter 60 mm and 45 mm were tried and speed ratio were considered to be too low to give enough impact required for shearing.

2.1.3. Design for pulley

Pulley of diameter 360 mm and thickness 50 mm was machined with mild steel. This diameter was arrived at being a function that will determine the weight of the pulley necessary for the impact required for shearing. The protrusion of gear box shaft was used to determine the diameter of the pulley. The keyway was cut to dimension 8 mm x 5 mm as dictated by the key on the gear box shaft.

2.1.4. Design for chute

A chute made of two angled-iron was welded to form a square of internal dimension 33 mm by 33 mm and length 1300 mm. The chute served as feeder or passage for the pairs of ball. The chute was reinforced with high manganese steel to withstand the shock load due to shearing effect on the balls.

2.1.5. Design for hammer/crushers

These were made of manganese steel, shaped and positioned on the pulley to effectively hit the middle of the pairs of balls. Manganese steel was used because of its higher hardness and tougher strength when compared to high chromium steel in which the balls are made of.

2.1.6. Design for stands

The base of the gear box was placed and bolted on top of a plate welded to the four legged stands which was made of 200 mm length angled iron mild steel. The legs were welded on the base plate taken into consideration the stability of the whole arrangements.

2.1.7. Design for base plate

A 15 mm thick mild steel 600 mm x 700 mm was provided as base plate. This ensured that the component units were rigidly mounted.

2.1.8. Design for holders

This was welded to the chute and the base to keep the chute in vertical position while the breaking operation is taking place. A 15 mm mild steel was used for this purpose.

2.2. Assembly procedure

After the selection of appropriate electric motor, gear box and construction of pulley, hammers, chute, stand, guide and base plate, the following procedures were followed in the assembly:

- Four holes of diameter 15 mm were drilled on the 10 mm thick plate around its corner in-line with the holes on the gear box base plate.
- The 10 mm thick plate was welded on the four stands while the gear box together with electric motor was bolted on the stand.
- The stands with the top plate was positioned and welded 185 mm to the left and 285 mm to the right along the breadth of the base plate and also 290 mm to the left and 200 mm to the right along the length.
- Two hammers/crushers opposite to each other, positioned and bolted to the pulley 5 mm away from the end of the pulley.
- The pulley was inserted and locked on the gear box shaft.

- The chute was held vertically on top of the hammer/crusher with a clearance of 5 mm and welded to the holder, while the holder was welded to the base plate.
- When all welds had been completed, the chute and holders were painted to prevent rusting.

Figures 2, 3 and 4 show the orthographic projection, exploded view and isometric drawing of the equipment respectively.

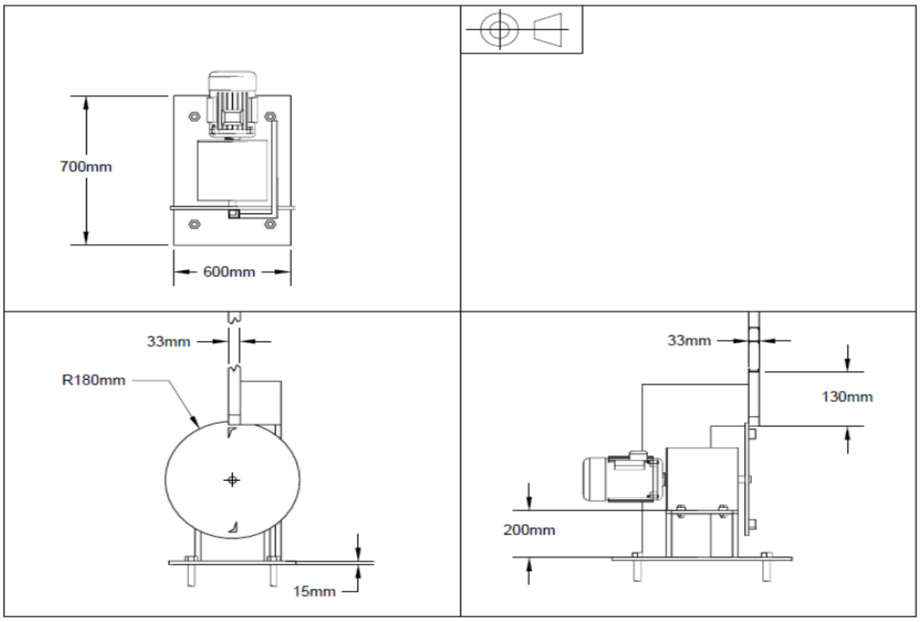

Figure 2 Orthographic Drawing

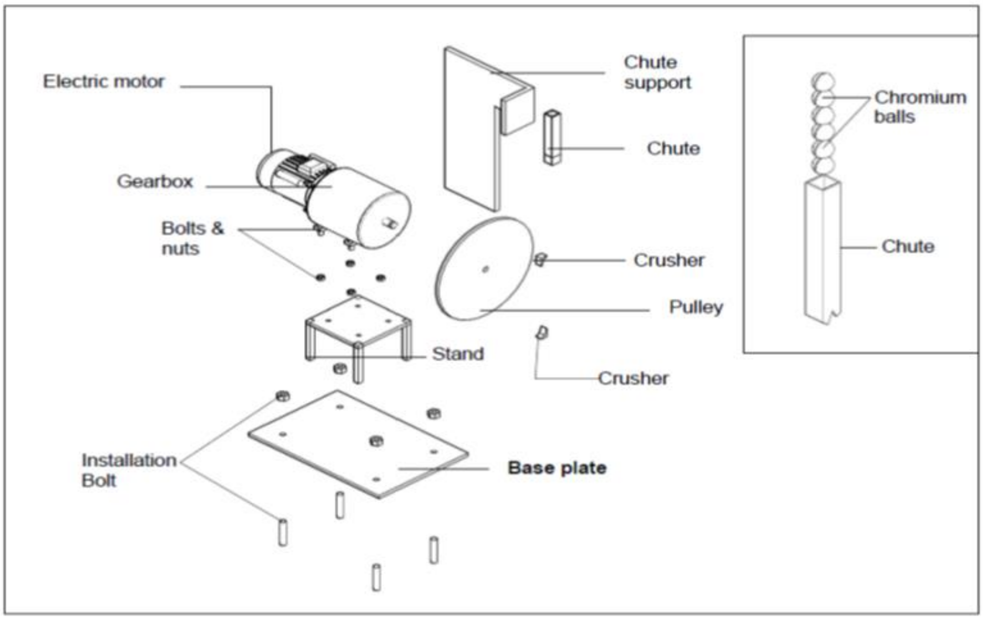

Figure 3 Exploded View

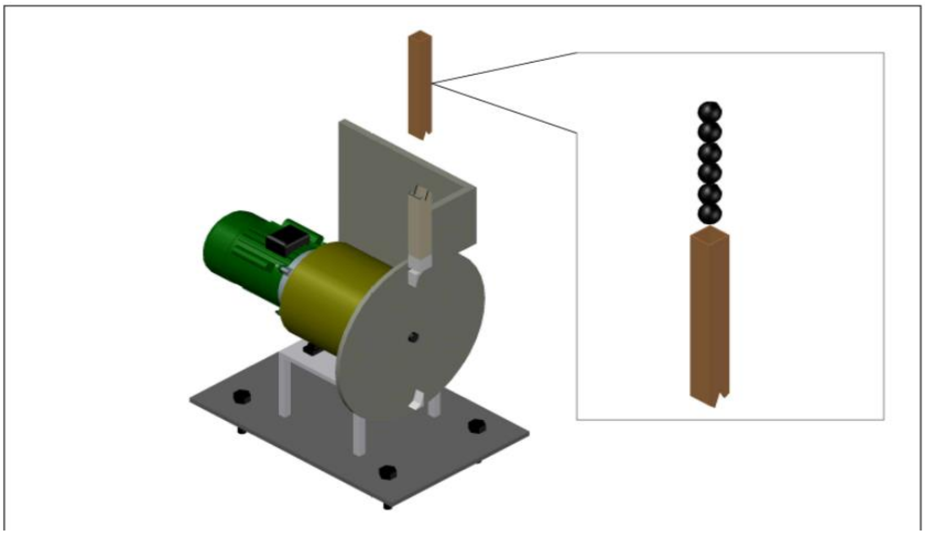

Figure 4 Isometric Drawing

3. Results and discussion

3.1. Determination of time for a cycle of operation

Total height of chute = 1300 mm

Total height of one pair of grinding media = 60 mm

Number of pairs of grinding media = $\frac{Total\ height\ of\ chute}{Total\ height\ of\ one\ pair\ of\ grinding\ media}$ = $\frac{1300}{60}$ = 21.67

This is approximately 20 pairs of grinding media.

Time for breaking one pair = 20 seconds (approximate).

Time for 20 pairs = 20 x 20 = 400 seconds = 6.67 minutes ≈ 7 minutes.

3.2. Determination of pulley speed

If, N_1= speed of gear box shaft, N_2 = speed of pulley, D_1 = diameter of gear box, D_2 = diameter of pulley.

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

D_2 = 360 rev/mins

3.3. Determination of shear stress obtainable from the hammer/crusher

Shear strength of high chromium steel = 379 N/mm^2. [6;7] and hardness of H_R = 36 [4]

For breaking the balls, the shear stress of the hammer/crusher (τ_c) must be greater than the shear strength (τ_b) of the grinding media.

Measured torque from the pulley of diameter 360 mm is 4.12 x 10^7 Nmm.

Shear stress of the hammer/crusher (τ_c) can be determined from following equation:

Torque (T) obtainable = $\frac{\pi\, \tau_c\, D^3}{16}$ [8]

Shear stress from the crusher τ_c from equation is about 450 N/mm^2. Since this shear stress is greater than the shear strength of the grinding media, the machine is capable of breaking the pairs of the balls effectively for a long period.

Impact force = Shear stress x Area of contact

F = τ_c x A

For a 10 mm x 10 mm hammer

F = 45,000 N or 4.5 KN

3.4. Operation procedure

- The machine assembly must be firmly bolted using the foundation bolts for good stability before the operation is commenced.
- Each pair of the grinding media is manually loaded into the chute. The chute can accommodate maximum of 20 pairs.
- Once the gear motor is powered, the clearance between the base of the chute and the shearing assembly will allow one half of the pair to come out of the chute.
- During operation, the hammer/crusher, bolted on to the pulley will rotate such that a hammer hit the adjoining area of the balls by impact force against the edge of the chute. The shear force will break the pair at the joint for the two balls to fall off to the ground for finishing.
- However, one complete rotation of the pulley will break two pairs of the grinding media since there are two hammers bolted on the face of the pulley.
- The next pair of grinding media takes its turn and the operation continues until all the 20 pairs separated.
- Each separated ball is grinded to remove flashes while other necessary finishing operations are carried out.
- Figure 5 shows the cast grinding media after separation.

Figure 5 Separated grinding media balls

4. Conclusion

A breaking machine has been designed and powered by a gear motor for effective and efficient separation of pairs of machine moulded grinding media. The breaking action of the machine was achieved by shear force and thus eliminated numerous problems associated with manual breaking using hardened and well sharpened steel cutter. This work has therefore been able to solve a long time local challenges being faced by an indigenous leading Foundry Industry in Nigeria. If this design concept is properly applied, it can be adapted to solve similar and related challenges in foundry and any other metal forming Industries.

Compliance with ethical standards

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Disclosure of conflict of interest

This is to certify that all Authors have seen and approved the article in the form presented for publication, and the article is the Authors' original work. We submit that this article has not received prior publication and is not under consideration for publication elsewhere.

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