ADDIS ABEBA UNIVERSITY, INSTITUTE OF TECHNOLOGY

TER OF ETHIO-MINES DEVELOPMENT STREAM OF MINERAL ENGINEERING

THE EFFECT OF GRINDING MEDIA SHAPES ON BALLMILL PERFORMANCE IN LIMESTONE GRINDING

A MASTER’S RESEARCH PROJECT SUBMITTED TO CENTER FOR ETHIC-MINES DEVELOPMENT, ADDIS ABABA INSTITUTE OF TECHNOLOGY, ADDIS ABABA UNIVERSITY IN PARTIAL FULFILLMENT OF THE REQUIREMENT FOR THE DEGREE OF MASTERS OF ENGINEERING IN MINERAL PROCESS ENGINEERING

BY

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DECLARATION

I, Wubsera G/Kidan), Hereby Decler that this Msc Research Project Entitled “**The Effect of Grinding Media Shapes on Ballmill Performance in Limestone Grinding.**” Has Been Developed by Me and has not been submitted to any other Institution for the purpose of obtaining any academic qualification. I affirm that the content is original and free from plagiarism, and all references to the work of other researchers have been properly cited.

Candidate’s Name	**Signature**	**Date**
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APPROVAL PAGE

This to Confirm That We have Reviewed the Msc Research Project and, In Our Assessment, It Meets the Necessary Standards of Scope and Quality Expected for a Master's Research Project for the Degree of Master of Engineering in Mineral Engineering.

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ACRONYMS

Nc = critical speed

D = in diameter of the mill

d = diameter of the ball

U = powder filling

Fc = the mill volume filled by powder

L = inner length of mill

rpm = revolution per minute

mm = millimeter

J = ball filling

psd = particle size distribution

E = specific grinding energy

I_p = 80% of product passing size

I_f = 80% of feed passing size

WI= Bond work index for a desired mill capacity Q

P = the required shaft mill power, $P = QE, Kw$

Q = mill capacity

ρ = Specific gravity of the ball

L=Internallengthofthemill

ABSTRACT

This study examines the effect of grinding media shape on ball mill efficiency by comparing spherical balls to worn, non-spherical balls in the grinding of limestone ore, an essential but energy-intensive process in which media consumption accounts for approximately 37% of operational expenses. To fill a significant research gap in media shape degradation, the methodology used controlled laboratory-scale batch grinding tests under identical conditions, with the resulting products analyzed through sieve analysis to determine particle size distribution (P80), and specific energy consumption and power draw were calculated using established comminution theory. The results demonstrated a clear and significant effect, showing that spherical balls produced a finer product (P80 of 80.72 µm) compared to worn balls (P80 of 86.46 µm), while also achieving this superior result with lower energy consumption (16.31 kWh/ton vs. 17.84 kWh/ton) and a reduced power draw (2.61 kW vs. 2.85 kW), indicating that worn balls lead to less efficient grinding and higher operational expenses due to their irregular shape and reduced effective surface area. Consequently, the study confirms that maintaining spherical grinding media is crucial for optimizing mill efficiency and profitability, recommending that industrial operations implement regular media monitoring and replacement schedules, while suggesting future research explore mixed media charges and interactions with other variables like mill speed and liner profile for a more comprehensive understanding.

Keywords: Grinding media, spherical and worn balls, limestone, grinding test.

CHAPTER ONE

INTRODUCTION

The operational and economic achievements of processing facilities are greatly impacted by milling, one of the most important but energy-intensive unit processes in processing minerals. The choice and use of grinding media have become crucial factors in improving the whole procedure performance and effectiveness in a variety of industries, including industrialized extraction of minerals as well as other uses that call for efficient mineral separation. The grinding media consumption itself could add significantly to operating expenses, highlighting the need for optimal media control and choice in order to increase productivity. In this study, I want to show and measure how a variety of media for grinding characteristics impact a ball mill's efficiency when reducing limestone, a key raw material for the production of cement. The study explicitly compares worn (non-spherical) balls versus spherical balls, looking at how each affects mill power needs, specific energy utilization, and product refinement. This investigation aims to demonstrate and quantify the effects of numerous media for grinding on a ball mill's effectiveness in reducing limestone, an essential raw material for cement manufacturing. The study examines the effects of worn (non-spherical) versus spherical balls on mill power requirements, particular power consumption, and product refinement.

1.1. Background of the Study

Even though several types of grinding balls are made from iron, steel, chromium alloys (Cr 15%–30%), ceramic, and pebble, it's crucial to remember that because of their inexpensive cost, milling media are utilized in an extensive number of milling purposes. (Willie Nheta , 2023). Furthermore, studies have been done to identify the optimal substances for producing improved grinding balls. (Mishra, September 2003) Therefore, wear, erosion, and attrition between the ore and the media used for grinding as well as between the mineral particles themselves are how the procedure of grinding is carried out, as demonstrated by Fig. 2.1(Brito-Parad, 12 May 2025). Mill configuration, liner layout, mill rate, ore mineralogical makeup, charging proportion, and the grinding medium characteristics are some of the factors that affect processing performance. The spread of output sizes, energy and power usage, and milling costs all affect how efficiently a cylindrical mill grinds. (Nyasha Matsanga .et.al, 2023). According to the researcher estimation, energy costs almost half of an industrial ball mill's operation, followed by liners at 13% and grinding media alone at 37%.This illustrates how media use equitably adds to the ore beneficiation procedure's operating costs (Gamal S. Abdelhaffez et al,, 2022,2,14) . As a result, it flourished as a field of research, and many articles about grinding media that were worth reading were produced. (D. Touil et al, 2008) Recognize that the material attrition problem is complex in both mills and is influenced by the constantly changing and complex operating conditions. Such characteristics include a portion of the crucial speeds (fc), the fractional ball filling (J), the total amount of solids, the distribution of ball and feed sizes, the powder filling (U), the percentage of the mill container packed by powders (fc), and the proportion of vital speed (fc). The researcher (Zixin Yin et al, 2024)), observed that as mill rotating speeds increased, the kidney area was occupied by larger balls, while the perimeter was populated by smaller balls. At intermediate speed, the charge dynamics produce a flawless transition state, which a representation of the uniform distribution was of contacts (Nyasha Matsanga .et.al, 2023). There does not exit an adequate study on how the media form affects the milling process. The primary emphasis of the present study is ball milling effectiveness. Sinnott et al., Matthew D. (2010). Media with a spherical shape, however, had noticeable differences in power consumption and loading position. Nonetheless, it is commonly known that highly irregular garbage balls, which fracture or break apart due to design flaws, reduce the operational efficiency of milling machines. (Xu Zhang et ale, January 2025,)

1, 2, Statement of Problem

These characteristics contain the portion of the mill container full by particles (fc), the percentage of the crucial velocity (fc), the percentage of the ball filled (J), the amount of minerals, the spread of spherical and /or worn balls and feed particle dimension, the particle filled (U), with total percentage of vital performance (fc). As an example, the investigators used (Ningning Liao, 2020) and (Paresh Rajodiya et al, 2025). Researchers discovered that with each one percent deviation from the mill rotation rate, 2% additional ball milling media are used. Balls migrate near the mill's edge, it is believed that relatively little grinding activity occurs at low mill rotation speeds. The kidney's microscopic media generate cubic shapes as they brush against one another. The most common media shape in tumbling mills is spherical balls. However, collision and various wearing mechanisms within the mill cause spherical balls to split into non-spherical fragments. Therefore, the mixture at any one-time mill charge ranges from worn irregular fragments to larger spherical balls. Few studies have been conducted recently to evaluate the effect of worn balls on mill performance. It is anticipated that more grinding by attrition will be encouraged by the additional surface contact created by polygonal balls and flat chips as opposed to the spherical media's sole point contact. However, worn balls can pack tightly, which would reduce the amount of empty space that could be used to grind the material. Polygonal (worn) media may have a greater surface area per unit mass, which could also mean that the ore supports the media more effectively, lowering media-to-media forces in the grinding zones. (Dokme 2015). The industrial mill milling efficiency was affected by the transformation of spherical shape into non-spherical fragments as shown in fig (2.2). Examine the effect of worn balls on mill performance while holding other factors constant allows my study to determine whether these factors can have a major influence on grinding efficiency, power consumption, cost savings, and the communication process as a whole.

1.3. Objective of the Study

1.3.1. General objective

To investigating the effect of grinding media shapes on ball mill performance in grinding of limestone ore.

1.3.2. Specific objectives

- ✓ To estimate the effect of grinding media shapes on product particle size distribution in grinding of limestone ore.
- ✓ To determine the effect of grinding media shapes on specific energy consumption in grinding of lime stone ore.
- ✓ To examine the effect of grinding media shapes on power draw by mill shafting chamber in grinding of lime stone ore.

1.4. Research Question

- ✓ How grinding media shapes influence product particle size distributions in grinding of limestone ore
- ✓ What is the significance effect of grinding media shapes on energy consumption in grinding of limestone ore?
- ✓ What is the significant effect of grinding media shapes on power draw by mill shafting in grinding of limestone ore?

1.5. Significances of the Study

This approach is undoubtedly increasing ball mill effectiveness, which can increase the financial performance of all mineral extraction plants. Companies will gain an advantage over their competitors and increase ball mill milling efficiency by reducing energy usage and reducing power and grinding costs .It can be useful to identify some hidden problems in the milling operations. Any other investigator with an interest in the same subject can use it as an entry point. Additionally, it will help any interested parties make sure that media-shaped activities affect milling efficiency and ball mill performance. The grinding media affects breaking properties, the size of particle distribution (PSD), and ball mill power consumption. Therefore, they ought to be as heavy as feasible and have the most surface area. They ought to have the greatest area of coverage and be as substantial as possible.

1.6. Scope of the Study

Limestone is used as a raw material in all Ethiopian industrial units, and by applying the same process; all marketable enterprises can be represented. Any connected businesses with cutting-edge technology could handle it, and it would affect all Ethiopian industrial facilities both public and private that use lime stone as a raw material. Data on the two types of grinding media forms (spherical and worn balls) and their effects on ball mill performance are being collected for the entire Ethiopian industry, which processes limestone grinding.

1.7. Organization of the Study

Six chapters make up this paper investigation. Background information on the mechanisms of operation of ball mills, the problem statement, the general and specific goals of the project, the project's significance and scope, and the definition of project terms are all covered in the first chapter's introduction section. This introduction chapter is followed by the second chapter, which describes the fundamental and pertinent literature on grinding media shape operations that has been previously completed by other researchers and reviewers. The study report's third chapter included the type of project work design used, the experiment sampling method, the methods of analyzing the experimental data, and the methods of applying the experimental work. The fourth chapter presented and analyzed the results of the experimental work in terms of tables, theoretically and graphically, and discussed the project terms and how they affect grinding efficiency. The final two chapters dealt with the general conclusion and recommendations of the project work.

CHAPTER TWO

RELATED LITERATURE REVIEW

2. INTRODUCTION

In this chapter, the key variables (grinding media shapes), such as spherical ball operation, worn ball operation, ball operation, and ball mill milling performance, are further clarified by different related literature. In this chapter the literature includes the main content, like theories, past studies, conceptual frameworks, and conclusions.

2.1. Theoretical Review

The importunateness of mineral processing is increasing the surface area of particle size distribution and minimizing energy consumption. Out of many factors that have influenced this process, grinding media shapes (worn balls) is one of them. The effect of grinding media shape on ball mill milling efficiency was certified through two experimental works. Following experimental work results, analyzed data, and findings of the work, we were convinced of the given study objective.

2.1.1. Theories of Comminution

Over decades there have been several pseudoscientific attempts to develop fundamental laws governing grinding, in the interest of understanding and improving grinding efficiency. Numerous investigators developed grinding hypotheses based on distinct pattern observation. These first attempts related the degree of grinding to the specific energy used in creating new surface areas of particles with a mean size of 80% passing screen sizes. These theories are of limited practical application, as size reduction is dependent on several factors that are not considered.

2.1.2. Bond's Theory

The Bond law of grinding has been widely used for mill sizing and design (Lameck, 2005). The model is an empirical equation based on analysis of data from laboratory and industrial mills. It is based upon the two-power calculation approaches used in the majority of ball and rod mill design processes. The determination of the power required to grind the ore from the given feed size to a specific product size. Selection of a grinding circuit with the mill design that will draw the required power. mill-sizing procedure, which is the mathematical form of Bond's (1952) mill-sizing procedure, his third comminution theory, estimates mill power per ton of 80% passing screen size of feed and product and is given as

$$E = WI \left[\frac{10}{\sqrt{I_P}} - \frac{10}{\sqrt{I_f}}\right] \quad \text{From the Rose and English method} \qquad (2.1)$$

Where E is specific energy.

Ip = 80% of product passing size, and If = 80% of feed passing size.

WI = Bond work index for a desired mill capacity Q and the required shaft mill

Power P is P = QE, k

2.1.3. Media Shape

As we conclude, apart from being relatively wasteful of energy, tumbling mills are also inefficient with regard to mineral liberation because of the indiscriminate nature of the grinding force. Accordingly, researchers (B. Shahbazi et al;, 2020) have made efforts to study the effects of media in an attempt to improve the grinding process and have come up with interesting results. Studies on media efficiency have concentrated on comparing their effects on the breakage distribution function and the selection function, ignoring other parameters defining mill performance, such as downstream processes. (S. Khumalo.etal 2019).Grinding media shape, among other parameters, has been reported as essential during grinding and has a significant influence on downstream processes such as flotation. It is also an influential parameter in mass transport, and research has shown that power draw is sensitive to media shape at different charge filling levels (Ngonidzashe Chimwani et.al, 2023) .It is said that the difference in media shape results in different surface areas, bulk densities, and contact mechanisms during grinding. Different grinding media shapes have different toe and shoulder positions in the mill, resulting in different power draws and load behaviors. Toe and shoulder positions are the angular positions at which the liner comes into contact with the charge and when the charge departs from the liners, respective (W.J. Bruckard et al, 2011) .According to friction coefficients between media and lifter and media–media affect the media position in the mill. Also, the surface area, which is affected by media shape, causes the charge to become more defiant and move between media layers, hence effectively lifting the load. (Ryo Miyazawa et al, 2020)The grinding performance for each specific shape from the literature compared to spherical balls. Spherical balls are mostly used for ball mill processes but are associated with high foundry production costs when compared to other types of media. They change their shape over time due to the wearing away of the outer layer. (Dokeme, 2015) Worn balls reduce the grinding surface area compared with spherical balls.

(Kiangi, 2006) However, there is a need to investigate the relationship between worn balls and mill speed, liner profiles, or filling ratios. (W.J. Bruckard et al, 2011)Another comparative study by indicated that tetrahedron shaped grinding media had a 14% more undersized product than spherical balls at different circulating loads rotating at the same mill speed. (ahya Kaya et al, 2024)For spherical balls, there is a substantial relationship between the ball filling and the toe and shoulder angles, and this type of media has been associated with the production of more slime when compared to worn balls. This type of media has been associated with the production of more slime when compared and lowest toe position compared to spherical and worn balls, at a critical speed of more than 60. (Karamjith Sharma et al, 2025) . For rates fewer than seventy percent of the crucial velocity, the toe locations of all media forms remained identical; however, the elbow locations for aged or round balls raised increasing charges of loading. Upon an alteration in mill velocity, the Cylpebs displayed a slight difference in shoulder locations. With velocities below 72 percent of their crucial velocity, Cyclopes absorbed greater torque than used balls, which were subsequently followed with round balls. Generated more large output than steel balls having the identical size and mass dispersion, according to a study, in contrast with round medium, this clypeus had a nine percent greater density of bulk with a 14.5% larger area of coverage.

(Paresh Rajodiya et al, 2025)All round balls exhibited the smallest head level among all of the completed tests. I was found the shoulder placements rely on mills fill addition to medium form. When the mill's loading grew, the foot's posture reduced and the arm posture climbed. (N. Hlabangana.et al, 2018) Cylpebs had the lowest power draw at speeds more than 72% of the critical speed and a more attracting behavior than worn and spherical grinding media. The reported that, at an equal specific energy input level, the cylpebs could produce a slightly less oversized mill product.

This was due to their greater surface area compared to spherical balls. Similarly, a comparative study with a laboratory tumbling mill under the same conditions (mass and feed load) showed a faster breakage rate for the clypeus one another (kagan kayacvi, 2001). Milling kinematics was an essential phenomenon which is influenced on the shape of media used throughout the grinding procedure. The Clypeus species demonstrated superior grind dynamics over spherical grinding media in a comparative analysis among spherical and non-spherical medium forms. Similar findings were found, indicating the cylindrical fracture more frequently then spherical based on the model's variables plus the specific rate of breaking. I got identical outcomes too. This was found that employing cylindrical grind medium rather than metal balls in a ball mill increased the particular fracture of cementing clinkers during grinding. During another investigation, the milling rates were improved by combining several forms and milling medium. Additionally, this has been shown that a variety in shaped media for grinding expands the turning area's dimensions, improving mill dynamics. Moreover, this, (Yıldız Yıldırım et al, 20121) According to studies, the granularity from the crushed output increased by ten percent when convex-concave ball were used in place from a portion of the round media used for grinding. nevertheless, because the convex-concave material for grinding moved unevenly, the milling effectiveness was reduced when more convex-concave balls were used in place of the round medium. Compared to circles, convex media used for grinding offer the greater particular region, which improves cutting effectiveness. During a different investigation, the electrical consumption of round balls or a complex polygon having media for grinding fill (J) = sixteen percent or 20%, to be exact, was barely different. It acted as round medium due of the ineffective interconnecting and the multidimensional polygon resulting from a decrease in feeding strength. For mill rates above 75 percent of its crucial rate, the energy used by a multidimensional polygon medium fell marginally when J increased to twenty-five percent. That resulted from the spheres within the center shrinking more. As stated in the findings, although a mill's fill capacity was inadequate, the geometry of the grinding medium had a minor effect upon energy consumption. Additionally, it said that compared to round balls, polygon balls had a larger interaction zone. (N.S. Lamec and M.H. Moys, 2006). Understanding how old balls affect grinding dynamics and deciding if intervention is required for preserving optimal grinding output are the primary objectives of the present study.

2.1.4. Grinding Media Action

The main goals of this research are to comprehend whether aged balls impact grind mechanics and to decide whether assistance is necessary to maintain optimum milling performance. K. P. Simba (2010). Additionally, a substance's level in reduction is determined by its likelihood of entering the area of grinding among the medium's forms and the likelihood that it will fragment there. As a result, a variety of devices that deform the particles and alter their forms beyond their degree of elasticity can be used to grind them. Contact and wear are the main ways that nanoparticles breakdown in a ball mill.

2.1.5. Impact Breakage

If pressures are typically delivered on the nanoparticle appear, breaking through effect, also known as breaking through compression as well, takes place. Fracture or cleavage is included within the fracturing process (Simba K. P., 2010). Only a small number of nanoparticles are produced when the amount of energy supplied is just enough to bring a relatively small number of areas of the particle to the fracture point, causing breakage via cleave. The dimension of the offspring is relatively similar to that of its parent particles. (by Zixin Yin et al, 2024) When gradual pressure is present, a break takes place, instantly relieving the particle's weight burden. When gradual pressure is present, a break takes place, instantly relieving the particle's weight burden. (S. Chehreh Chelgani et al, 2020) A comparatively tiny part of a molecule gets cut out, producing an element that is nearly the same size as before, an occurrence known as chipped. However, (Tomach, 2024) claimed that if the input effort is significantly greater than what is needed for fractures, fracture via shattering happens. A relatively huge amount as nanoparticles having an extensive variety of size is a consequence of several locations in the molecule experiencing overload in these conditions. This happens when there is swift loading, like in a high-velocity impact, and its breaking mechanisms that in fig (2.1)

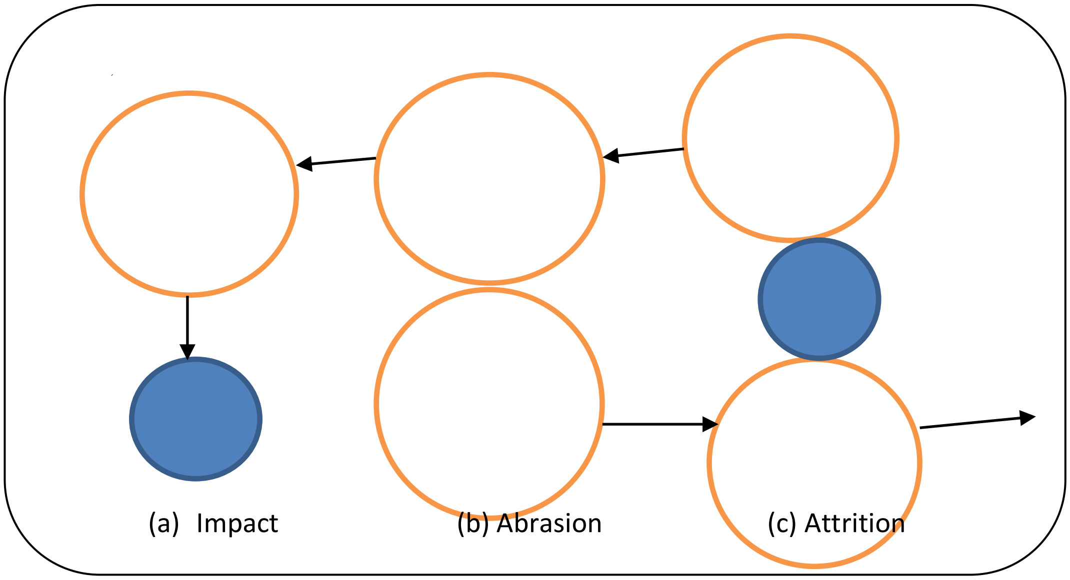

Figure 2.1 Mechanisms of breakage grinding medias (Zixin Yin et al, 20)

2.1.6. Breakage by Attrition

Because it determines the type of goods produced and the degree of wear on the shell liners, the mill's speed of operation is crucial. Determining the speed that is critical when the grinding media will just stay on the shell for the entire cycle is also typical. The feed particle movement is seen in the face in fig **(2.2**

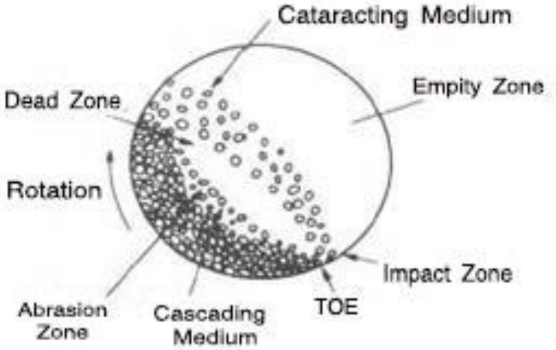

Figure 2. 2 *Motion of charge (grinding media) tumbling mill (Simba K. P., 2010)*

$$\text{Critical speed rpm} = \frac{42.3}{\sqrt{D_2 - d}}\ \text{rpm}$$

Which is D is the largest possible ball size in meters while D represents the inner mill size. Filling circumstances including the plant's lift type of seed determine the proportion of crucial velocity when these operations take place.

2.2. Conceptual Framework

The simplest way of demonstrating the theories by figure in a form that everybody can understand is called conceptual framework. In the study, the shape of worn spherical grinding media is taken as the independent variable, while the performance of the ball mill is considered the dependent variable. So this figurative demonstration of the conceptual framework of grinding performance determinations of media shapes on ball mills is demonstrated in. Fig (2.4)

The independent and dependent variable of the conceptual framework the study are;

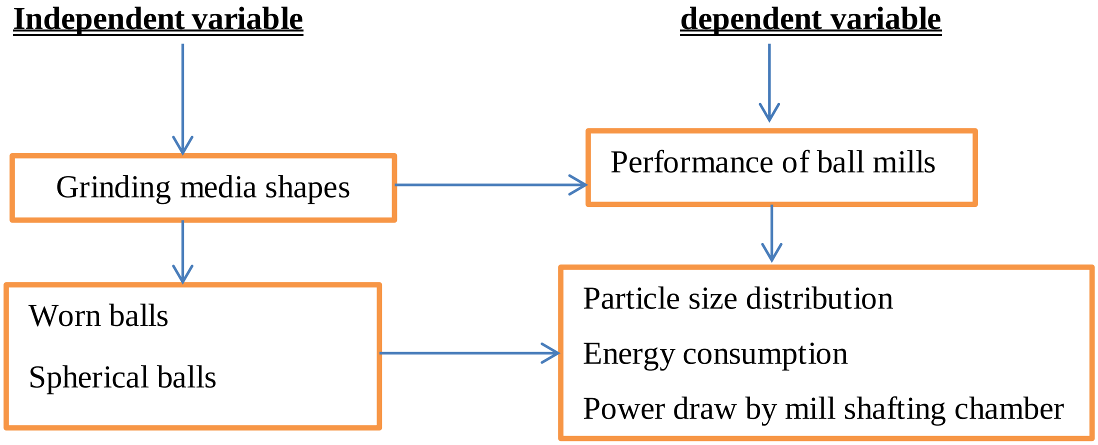

Figure 2. 3 the independent and dependent variable of the conceptual framework the study

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The block diagram of Conceptual Framework the study

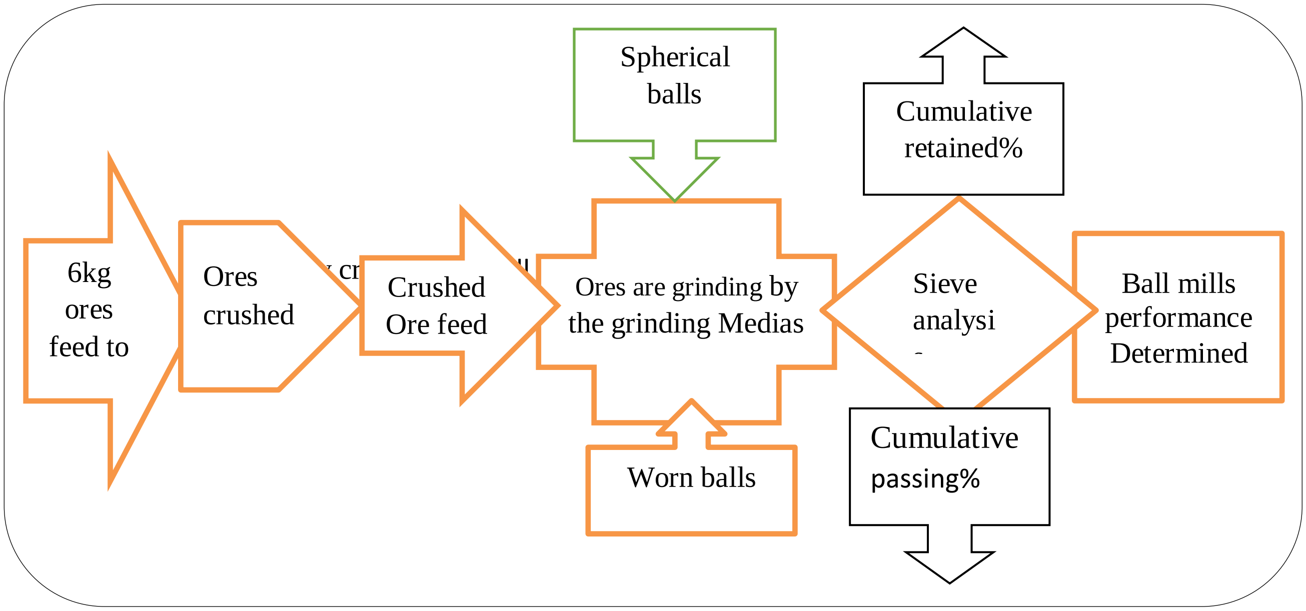


Figure 2. 4 the block diagram of Conceptual Framework of the work starting to ending

CHAPTER THREE

METHODOLOG OF THE STUDY

3. INTRODUCTION

This chapter will describe the laboratory grinding mill. Also, the grinding media and the feed samples used for the batch tests will be present. Additionally, the tests will be performed to generate and explain the experimental data. The method will be used to characterize the breakage properties of the limestone as well as the milling kinetics of the grinding media shapes, and the mixtures of these grinding media shapes will be present.

3.1. Experimental Equipment, Raw Material and target samples

Table 3. 1 *Experimental Equipment, Raw Material and target samples*

No	Equipment type		Unit	Total	Remark
1	Jaw crusher		No	1	Equipment
2	Mill		No	1	Equipment
3	Grinding media	Spherical balls	No	68	Target samples
		Worn balls	No	68	Target samples
4	Sieves		No	6	Equipment
5	Pane		No	1	Equipment
6	Lime stone		Kg	6	raw material
7	Digital balance		No	1	Equipment
8	caliper meter		No	1	Equipment
9	Meter		No	1	Equipment

Table 3. 2 *Experimental design of target sample operational conditions*

No	Operating condition		Unit dimension	Remark
1	Mill dimensions		1.Innerdiameter (D), 2.Length, 3.Volume, dm3 4.critical speed(NC), 5 mill speed	0.54 0.31
2 3	Medias	(spherical balls)	1.Material 2.Diameter range (d), mm 3.Specific gravity (kg/m3) 4. Void age Filling ratio (%) 5. Filling weight (kg)	alloy steel (6.85,10.52,23.64)mm 7.85 0.4% 1.4
		Non-spherical or worn balls	Material Diameter range (d), mm Specific gravity Void age Filling ratio (%) Filling weight (kg	Alloy steel (6.51,8.59,13.43) mm Approximately 7.85 Approximately 0.36 1.4
4	Grinding material		Material Specific gravity (kg/m3) Humidity (%) Maximum particle size, m	Limestone 2.6 – 2.7 1 3.5mm
5	Test conditions		Ball filling, J Powder filling, U Mill speed	20 % of mill 75 % of mill 75 % of critical speed (Nc)
6	Liner configuration		Number Shape	12 trapezoidal, 20 mm elevation 50 mm base width

$$N_c = \frac{43.3}{\sqrt{D-d}} 43.3 \quad \text{rpm (D, d in meter)} \quad (3.1)$$

$$\text{Charge mass (Kg)} = 0.6\text{j}\pi D^2 L^4{}_P \quad (3.2)$$

$$J = \left(\frac{{}^{mass\ of\ balls}/_{density\ of\ balls}}{Volume\ of\ mill}\right) X \left(\frac{1.0}{0.6}\right) \quad (3.3)$$

$$U = \frac{f_c}{0.4J} \quad (3.4)$$

$$f_c = \frac{{}^{mass\ of\ powder}/_{powder\ density}}{mill\ Volume} \quad (3.5)$$

U represents the percentage of powder-filled gaps within the particles of grinding media when they are at rest. A powdered media with a grinding ratio between 0.6 and 1 yields effective breakdown within the mill..Tembo, P. M. et al. (2019)

3.3 Laboratory Grinding Mill Configuration

The mill was used to carry out the necessary batch grinding tests on the lime stone sample from the plant or laboratory. This mill is fitted with twelve equally spaced trapezoidal lifters and is driven by a power of 2.5 kW variable speed motor will be mount on a mill rig. The internal dimension of the mill is approximately 0.54 m diameter and 0.20 m length. The lifters are 20 mm high with 45 degrees face angle and 50 mm base width. Table 3.2 gives some specifications about the mill and the operating conditions as defined for the experimental work.

3.4 Experimental Method

In this study approximately 6 kg of limestone rocks originated from the country rocks of the Abay Beriha mine, which is located in the district of Dejen town and surrounding areas, and was used as sample preparation. It was done in two rounds as follows. The first round experiment were which was hold media of spherical balls and the second round experimental was hold media of worn balls . The rocks were crushed with jaw crushers, a particle size of 3.5 mm being enough to be done with grinding processes. The crushed particles were fed to a ball mill in order to be ground, and the obtained product particle size of the sample ore was 3.5 mm. Each round of the experiment was used to determine the initial particle size distribution by means of the dry sieving analysis method and by using Bond's Law of the model. As a result, the milling performance of the ball mill will be concluded through the mathematical calculation of energy consumption and the power drawn by the mill shafting and product particle size.

CHAPTER FOUR

4. DATA PRESENTATION AND RESULT ANALYSIS

The listed equipment below the figures is collected, measured, and quantified. Using these materials and equipment, the experimental works were done in two rounds. Each round of experimental work was done with the same method except for the grinding media difference (worn balls and spherical balls) in all rounds of experimental work. 1400 grams of crushed limestone ores with a particle size of 3.5 mm are fed to the mill (operation media). The feeding ores were ground by the spherical and worn balls media. This process was performed with a 2.5 kW power supply and a speed of 3.5 rpm for 30 minutes. The ground limestone ore was shaken with five sieves and one pan for 10 minutes, as shown in fig. (4.1). these experimental work results were analyzed with a sieve as retained (coarser) and passing.

Spherical **Worn ball**

Sieve **Jaw Crusher** **Grinding Mill**

Figure4. 1 Laboratory equipment's and grinding media parameters

In these experiments two grinding media samples were selected, and two experiments were studied, while at the end of the experimental works particle size distribution analysis was analyzed, and energy consumption and power draw were calculated. A 6kg of lime stone was brought Abay Berha the quarry site of Dejen cement factory and the grind media samples were available in AAIT laboratory class. This black rock was crushed with a jaw crusher up to 3.5 mm product size. Out of 6 kg of crushed ores, 2800 gm of crushed limestone ores were used. In each round of experiment 1400gm feed to the mill media 1400gm in order to grinding and obtained the required product size of the feed nearly75% of finer. In these experiments two grinding media were selected, and two experiments were studied, while at the end of the experiment particle size analysis was analyzed, and the milling performance of the mill was determined through mathematical calculation of energy consumption and power draw by the mill shafting chamber during the grinding processes.

4.2. Experiment One (Sample of spherical Balls)

For this experimental work, I provided all experimental work equipment and other entailed materials and raw materials shown in fig. (4.1).The given system is designed as a pinion gear system. The feeding system is designed as batch working. Based on engineering estimates of the proportionality mixture of the feed ore, grained media, and volume of the ball mill, the grinding operation lasted up to 30 minutes. The ground ores were shaken up to ten minutes with five sieves and one pan. This shack's ores were analyzed as retained and passed. Coarser and finer) as shown in table (4.1). This sieve analyzed ground product of feed (retained and passed or coarser and finer) and calculated as a percentage and cumulative percentage retained and passed value related to the feed amount to grinding media. In table (4.2), this percentage value expiration of the ground ores enables us to easily understand the particle size distribution of ground ores, the energy consumption of grinding media, the power draw by the mill shafting, and the average of the p80% passing particle size in graphs (4.6) and (4.7) to gather. From the point of view of these graphs, it is possible to understand the determinate value of grinding efficiency (energy consumed and power drawn).

4.3. Experiment Two (Sample Of worn Balls) The second experimental work accomplished In the same way as the operating system of the first experimental work except for grinding media (worn or spherical) and product output (retained and passed (finer and coarser)). Table (4.3) (retained and cumulative) percentage; (passed and cumulative) percentage value table (4.4) particle size distribution fig. (4.4); energy consumption fig.(4.5); and power draw by mill shafting. Fig (4.6) Spherical balls of ground Media was mixed with the feed of limestone ore to the volume of 0.0402 m^3 of milling operating media. Then the ground limestone ore powder was separated as coarse (upper) and fine (lower) by sieve analysis, a separated method through the five sieves and one pan. As a result, the required product of particle size distributions was obtained as shown in table (4.1) & table (4.3) for experiment one and two, respectively.

4.4 Experimental work Results

The feed of 1.4 kg limestone ore to operational parameters (ball mills) ground and output results are presented as coarser or retained and finer or passing using the five sieves and one pan in tables (4.1) & (4.2) for the two grind media samples (spherical and worn) balls in experiments one and two, respectively. The words "coarser" and "finer" imply the particle size distribution of the ground ores or the comparison of increasing surface area of ore particles. Particle size distribution (PSD) is defined as separating coarse (retained) and fine (passing) particles and quantifying the proportions of coarse versus fine particles. In this work, ground product using layers of screens with decreasing mesh sizes was done using these sieves, as shown in table (4.1) and table (4.2), which show experiments one and two, respectively .In addition to this implication, sieves use cut size (P80 reference sieves) to regulate feed into secondary grinding equipment like ball mills. This balance ensures steady-state conditions and effective size control. Sieve analyses as coarser and finer surface area for experiment one

Table (4. 1 *)Sieve analyses' as coarser and finer surface area for experiment one*

Sieve Size in(µm)	**Retained (g) weight uppercases**	**Passing weight (g) lower coarse**
1000	571	829
710	133.8	690.2
500	61	634.2
250	128.4	505.8
100	92.8	413
<100	151.1	261.9

Table 4. 2 *Sieve analyses' as coarser and finer surface area for experiment two.*

Sieve Size in (µm)	coarser weight(g)	finer weight (g)
1000	556.4	843.4
710	126.4	717
500	55.5	661.5
250	132.9	528.6
100	89.3	438.7
Pan (<100)	130	308.7

4.5 Analysis of Experimental Data Results

The descriptions and compression of the output results of the two experimental work samples in table form, graphically, mathematically, and theoretically, lead to the finding of the study's objective. Therefore, based on the experimental data results in tables (4.1) & (4.2), the objective of the study was achieved as such analysis. The analyzed ground ores, as coarse and finer with sieves in tables (4.1) & (4.2), were expressed as the percentage of retained and passing, and also the percentage of cumulative (retained and passing) was an initial. As a result, the percentage retained-passing and the percentage cumulative retained-passing below

***Table 4. 3** Retained and passing ores in percentage of experiment one*

Sieve Size (µm)	% Retained	Cumulative % Retained	% Passed	Cumulative % Passed
1000	40.79	50.20	59.21	11.41
710	9.56	11.77	90.44	17.43
500	4.36	5.37	95.64	18.44
250	9.18	11.30	90.82	17.51
100	6.57	8.09	93.43	18.01
<100 (pan)	10.79	13.28	89.21	17.2

***Table 4. 4** Retained and passing ores in percentage of experiment two*

Sieve Size in (µm)	Percentage of retained	Percentage of passed	Percentage of Cumulative Retained	Percentage of Cumulative Passed
1000	39.74	60.26	51.04	11.54
710	9	91	11.56	17.43
500	3.96	96.04	5.07	15.39
250	9.49	90.51	12.19	17.33
100	6.38	93.62	8.19	17.94
Pan (<100)	9.29	90.71	11.93	17.37

4.5.1 The Graph of Particle Size Distribution

The size of the particle dispersion and the sieve size relation in the two experiments are identical, as illustrated in figs. (4.2) and (4.3). This implies that when a sieve size shrinks, the overall percentage passed (P80) likewise shrinks. As anticipated, the slope is sharp at larger dimensions (1000–500 µm) and gradually flattens toward smaller dimensions, indicating that tiny particles go through fewer sieves. Following milling, the SD curves clearly shift towards finer particles. Large feed particles are effectively reduced to smaller particles by the grinding process when a high accumulated proportion of the material goes through lower screen sizes. The first feed size is much larger than the expected P_{80} (the size of the particle that occurs during 80% passed), indicating success.

(4.2) .The graph of p8o% passed vs. sieve size for experiment two

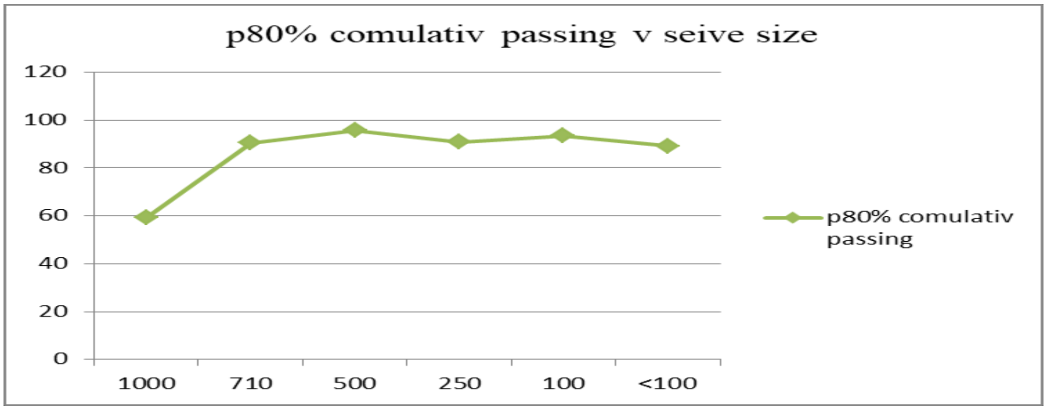


***Figure4. 2** the graph of 80%passed vs. sieve size for experiment two*

4.5. 2, Energy Verse Particle Size Graphs for p80% Passed

The cumulative percent passing (P80) likewise falls as the sieve size does. As anticipated, the slope is steep across bigger sizes (1000–500 µm) and gradually flattens toward finer sizes, indicating that finer particles go through small screens. Following milling, the SD curves clearly shift toward finer particles. Large feed particles are successfully reduced to smaller ones by the grinding process when a high accumulated proportion of the material passes through the lower sieve sizes. Effective particle size reduction is confirmed by the predicted P80% (the particulate size at which 80% passed), which is much smaller than the starting feeding size as indicated hereunder.

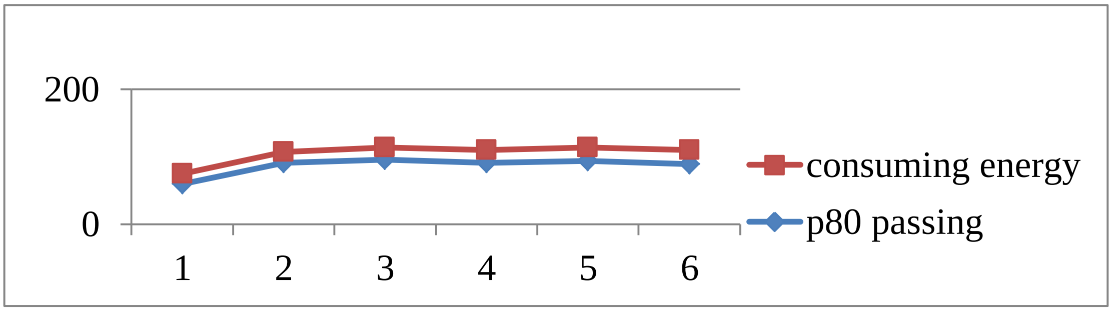


***Figure4. 3** consumed energy vp80% passing product size*

The energy consumption versus p80% graph passed the first experimental particle size test. Usually this graph displays a reverse connection, with power demand rising as P_{80} falls (signaling a better output). In accordance with the milling hypothesis, which suggests smaller particles require more breakage energy, this pattern demonstrates that more energy is needed to accomplish finer grinding. With no unusual demand for energy spikes, the grinding system's behavior is consistent with anticipated efficiency, suggesting effective operating within design parameters. Optimizing the goal P_{80} value is crucial for minimizing mill power consumption while maintaining acceptable output sizes. Targeting extremely small particles should only be done when absolutely required due to the power expenditure.

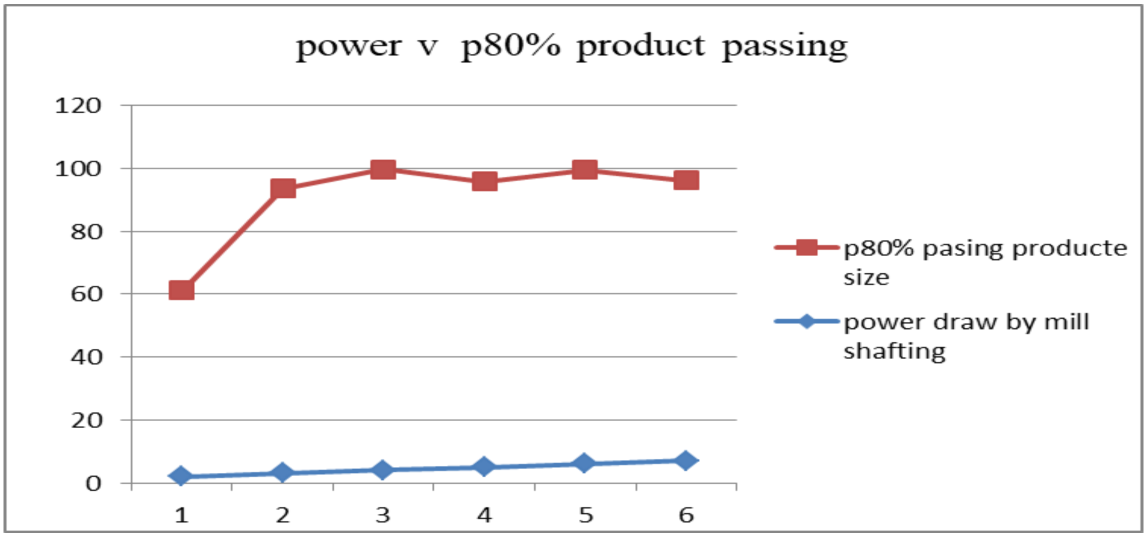
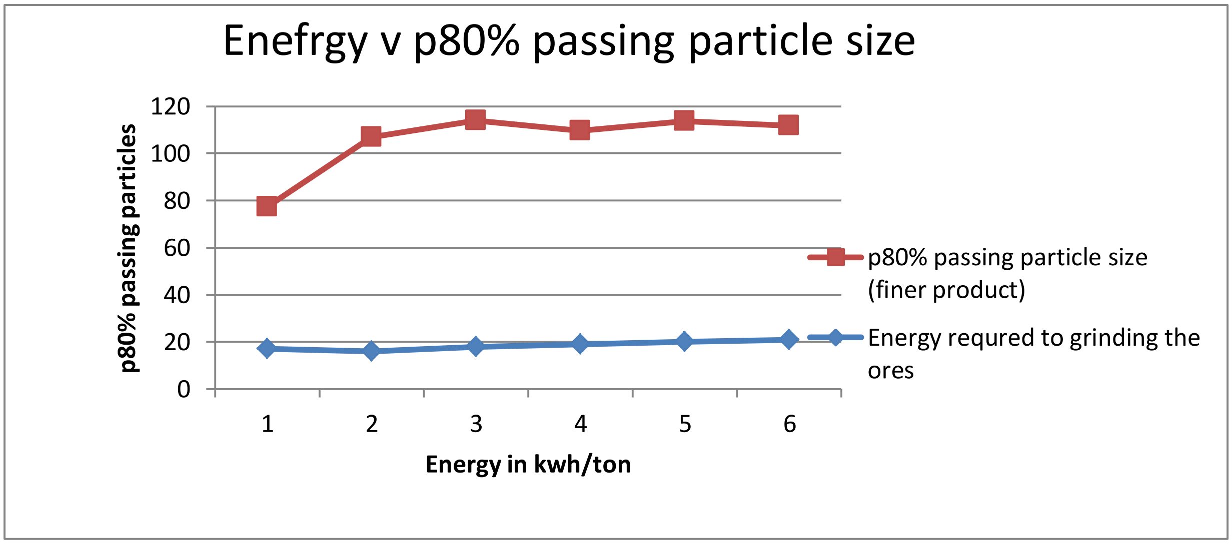


Figure4. 4 *the power draw by mill shafting chamber v p80% product passed particle*

Figure4. 5 *Energy consumed vs.p80% passed particle size for experiment two*

The second experimental work accomplished In the same way as an operating system, the first experimental work except for grinding media (worn or spherical) and product output (retained and passed (finer and coarser)) table(4.3) (retained and cumulative) percentage; (passed and cumulative)



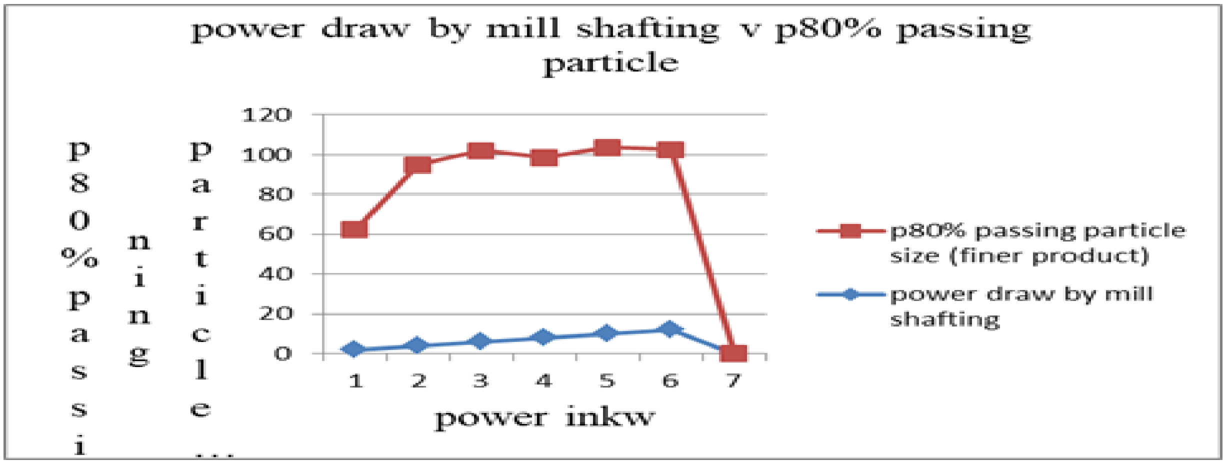
percentage value table (4.4), particle size distribution fig. (4.4) eneregy consumption fig. (4.5) and power draw by mill shafting. Fig. (4.6) Spherical balls of ground Media were mixed with the feed of limestone ore to the volume of milling operating media. Then the ground limestone ore powder was separated as coarse (upper) and fine (lower) by sieve analysis separated method through the five sieves and one pan. As a result, the required product of particle size distributions was obtained as shown in table 4.1 & table 4.3 for experiments one and two, respectively. Energy vs. P80% Particle Size Distribution (Finer Product) has an inverse relationship. In order to achieve a finer product, grinding size requires significantly more, exactly more, energy. The second round experiment result convinced

Consumption of energy and 80% product size. Fig 4.5 Energy consumed vs. 80% passed particle size for experiment two

4.5.2. Power vs. P80% Passing Size

As the 80 percent passed size falls, power demand likewise rises. The tendency highlights the need for the mill's driving system to provide additional mechanical input in order to reduce particle size. This confirms what is frequently observed in milling processes: thinner outputs were there.

Figure4. 6 the graph of the power draw by mill shafting vs.p80% passed particle size



4.6. The Mathematical Calculation of Determent Value

The determinate parameters of ball mill grinding performance are energy consumption and power draw by mill shafting during grinding. Based on these parameters, the effect of media shape (worn and spherical) balls on ball mill milling efficiency is determined below the graph as Shawn. Figure 4.1 The mathematical calculation of e (energy) and p (power) for experiment one: based on the above tables and graph result values, let's determine the values of F80 & P80 particle size in order to calculate (E) and the power draw by mill shafting (P) 80% passing.Particle size of 80% is obtained = 2.27 mm. E = 16.31 kWh/ton. P = 2.61 kW.In the same way as the experiment sampled one, let the determined values of F80 & P80 particle size be in order to calculate (E) and the power draw by mill shafting (P). 80% passing lies between:. 1000 µm (49%) 80% passing lies between 1000 µm (49%).(Exceeds 80%, so we need to extrapolate above this point)Particle size of 80% = 2.24 mm, E = 17.84 kWh/ton, P = 2.85 kW

Figure(4. 7) Comparison of particles the two grinding Medias

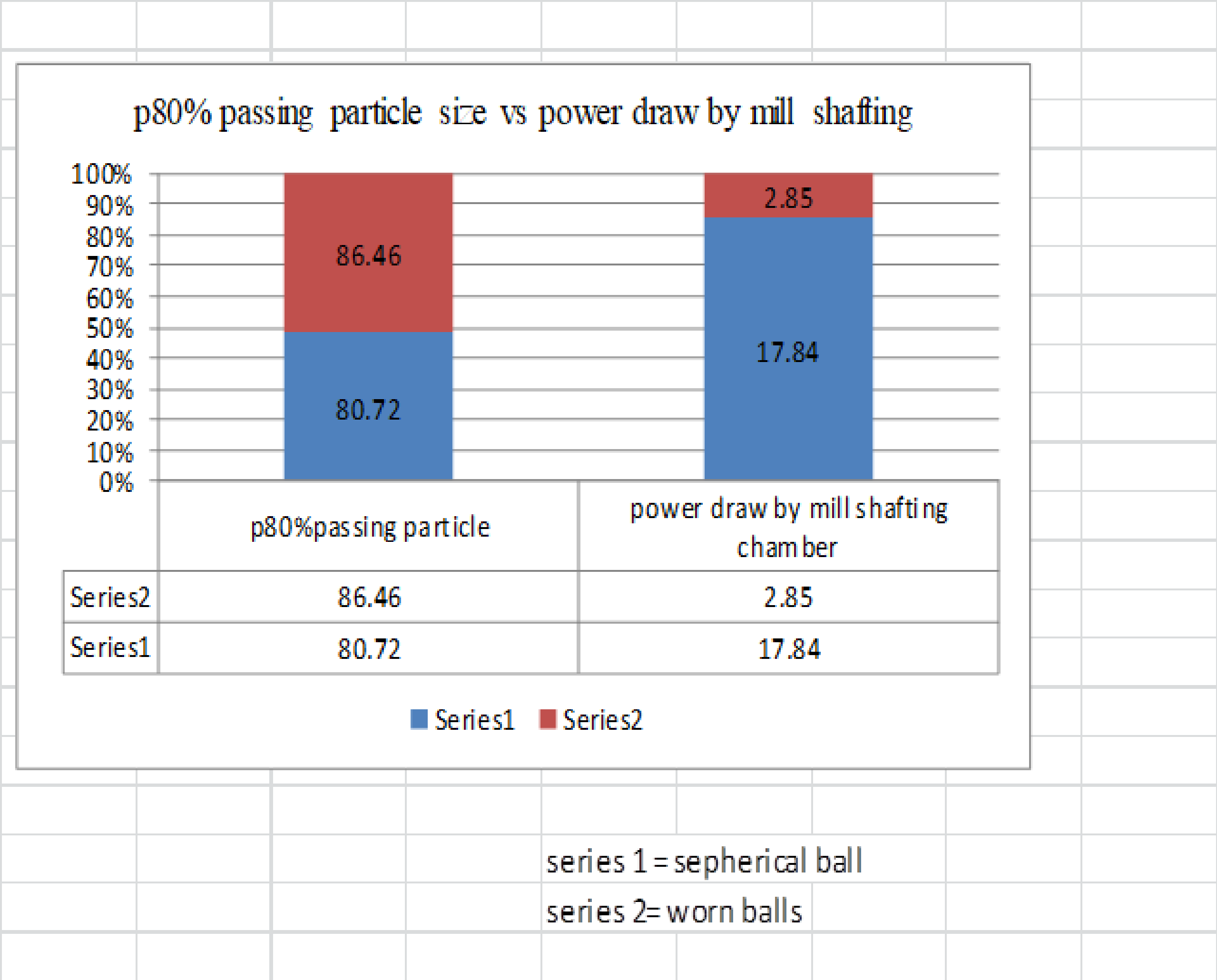


Fig (4.8)

Comparison of product passed (finer) particles the two grinding

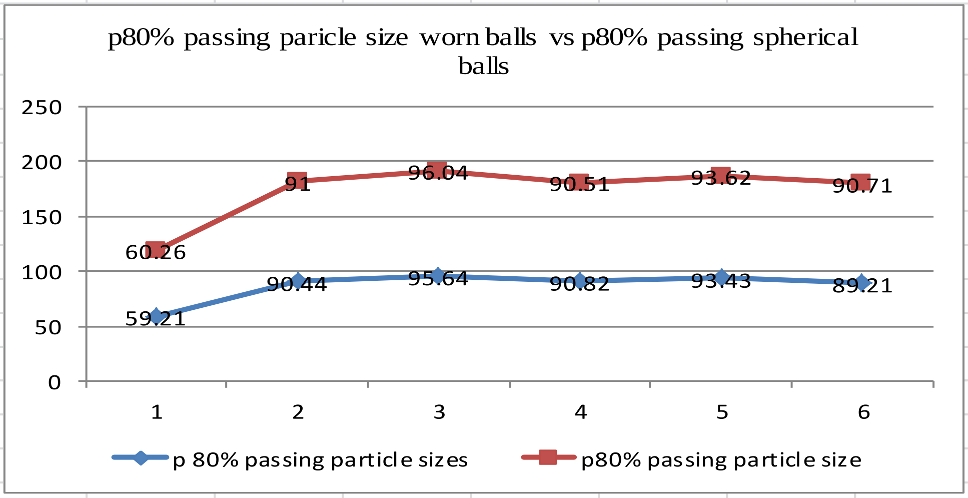


Table (4. 5) findings of the study

Operational parameter	**Shapes of media**		**Comparison of findings**
	Worn balls	**Spherical balls**	
Average of particle size	2270 µm	2240 µm	Item worn balls have larger particles than spherical balls. The spherical ball had a smaller particle size than the worn ball, but the worn balls required more energy to reduce the particle size. Grinding worked well and didn't require more energy.
Average of p80% passing particle size	86.46µm	80.72 µm	On average, spherical balls generate finer particles than worn balls (80.72 < 86.46), which indicates improved grinding efficiency but ineffective grinding in worn balls. extra energy required to pass 86.46 and lower p80%
Energy consumption	17.8kwh /ton	16.61kwh/ton	Compared to worn balls, spherical balls take less energy per ton to produce finer particles. However, this also implies that they are more effective if a high-quality output is required.
Power draw mill shafting chamber	2.85kw	**2.61kw**	Because of their superior shape and motion, spherical balls use power more efficiently than worn balls, consuming 0.17% kw less.

CHAPTER FIVE

5. DISCUSSION

5.1. Sieves

In particle size distributions (PSD), coarse (retained) and fine (passing) particles are differentiated, and the ratios of coarse to fine particles are measured. Such sieves were used to create the work ground end product, which consists of layers of screens with progressively smaller screen sizes, as shown in table 4.2 below and table (4.4) for experiments one and two, respectively. Furthermore, the cutting size (P80 benchmark sieves) is used by sieves to control feed into ball mills and other secondary grinding equipment. Stable circumstances and efficient size control are guaranteed by this balance.

5.2. Worn Balls

This study's primary goal was to find out how worn grinding balls, as opposed to spherical balls, impact a ball mill's milling efficiency. According to experimental findings (line and bar graphs), worn balls drastically lower grinding efficiency, resulting in higher energy costs and lower-quality products. Among the main effects of worn balls are Loss of Spherical Shape: Balls become less spherical as they deteriorate, which lowers their grinding area of the surface. Because of this, the mill is less able to effectively break out fragments, which leads to larger sizes of products with reduced output. According to studies, spherical balls can generate up to 5.74% finer product than worn balls while using 1.23% less energy and 0.24 less power draw by the mill shafting chamber. Increased Energy Consumption: Worn balls transfer energy less efficiently, requiring more power. To achieve similar grinding results this increases operating costs and places additional stress on the mill components.

Altered Load dynamics irregularly shaped balls because uneven load distribution and motion in the mill, disrupting the grinding process and potentially damaging liners increased wear on liners: worn balls cause higher impact forces, accelerating liner wear and increasing maintenance costs and downtime. Product contamination: worn balls can shed metal fragments into the final product, especially problematic in industries requiring high purity.

5.3. Spherical balls

Improved areas of surface that contact physics-consistent surfaces of contact and uniform loading behaviors are provided by round balls.It enhances total milling efficiency by supporting steady power drawing or constant braking dynamics. More Energy and Smaller Result: According to data from experiments, round balls require roughly 1.23% more energy and provide an end product that is roughly 5.74% finer than worn balls of comparable mass. Other research shows that spheres use less power than cubes or ellipsoids. Best Breaking Ratios: In similar circumstances, spherical balls typically provide superior particular breaks or throughput, even though certain other forms (such as cylinders) have more surface area.

CHAPTER SIX

CONCLUSION AND RECOMMENDATIONS

6.1. CONCLUSIONA

Study was done throughout this period to raise the standard of milling medium. In order for them to survive the extremely corrosive and abrasive conditions found in the ball mill. In order to reduce slurry contamination and avoid affecting process steps like flotation, media for grinding was additionally enhanced. Chrome-plated iron balls are utilized in situations whereby fluid pollution ought to be kept to a minimum, while bright white cast irons are employed in extremely rough settings. To ascertain the impact on the microstructure of the grinding media, research has been done on the manufacturing methods, including forging and molding, as well as the thermal treatment procedures. A study on milling media that endure abrasion wear and have an extended lifespan is currently being conducted; nevertheless, clypeus, ovals, cubes, and reduced cones are among the various forms of milling media that have been produced and can contend with the widely employed round media for milling. The distribution of the size of the media used for grinding is more important than its density, shape, and toughness, and the effectiveness of a ball mill is also influenced by operations like packing, pH, and grinder velocity, as well as wear. The best grinding media have the lowest levels of wear, as they last longer and generate little material that impacts subsequent operations. To gain a thorough grasp of the milling procedure, numerous aspects of ball milling performance as a consequence of the medium of grinding still require investigation. To improve mill effectiveness, more ought to be done to utilize the characteristics of ground material, including shape, dimension, and roughness. Because the majority of currently used grinding media, such as high-chromium cast iron and high-carbon low-alloy steel, include some amount of both austenite and marten site. To reduce grinding wear in the ball framework, iron oxide and ferrite sites of high toughness ought to be utilized. Large grinding component rates of wear are produced by abrasive ores like copper and gold. Particle dimensions and power consumption in ball mills are influenced by the form of the milling material, as Graph 4.4 illustrates. Relative to used balls, round balls produce an end result that is roughly 3% finer and uses 6% less energy. Although the balls employed in this study were completely worn, industrial mills frequently use a combination of spherical and worn media. For better outcomes, experiments utilizing a mixed-medium approach ought to be incorporated into future research. Findings from experiments verify that the geometry of the milling medium has a major impact on milling effectiveness. After a while, the medium degrades, decreasing the cutting surface area and raising power consumption. To preserve efficiency, old balls ought to be taken out at frequent intervals. Although round balls are the most popular, various forms having pressure and abrasion resistance, such as ellipsoids, cubes, and cylinders, are also being created. Under some circumstances, these can rival traditional media. The vast majority of fragments remained on the 1000 µm sieve in the two study works, indicating rough milling; finer particles less than 100 µm comprise approximately 10.8% of the total; consumption of energy rises with decreasing particle size as predicted, and the power consumption rises for smaller fragments, indicating higher energy demand for fine milling; and the use of damaged balls may lead to inadequate milling at the smaller dimensions.

6.2. Recommendations

Enhancing productivity is crucial for income because milling activities account for more than half of a plant's budget. Create superior studies with more sophisticated measuring and categorization for plants utilizing used balls. Perform numerous parameter analyses customized for specific substances. Utilize durable materials, maximize replacement times, and keep an eye out for pollution to guarantee the purity of the output. Test variables such as loading proportions, lining dimensions, and varied grinding rates ought to be included in future research since they can provide a greater awareness of milling effectiveness. Frequent observation, routine inspection of the grinding medium, and quick replacement of worn balls Improved ball structure and use of media of greater resistance to wear for a longer lifespan. Maintained ideal mill rate and loading under controlled working circumstances to cut down on needless wear.

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