GERMAN - MONGOLIAN INSTITUTE
FOR RESOURCES AND TECHNOLOGY

The present work was submitted to the Faculty of Engineering

Study on the ball mill liner consumption in the Enrichment Factory of Erdenet Mining

Bachelor Thesis

by

Jalbiidandar Sambuunyam

Supervisor 1 / Examiner 1 Prof. Dr. Sungchil Lee

Supervisor 2 / Examiner 2 M.Sc. Battsengel Dashdorj

2023

Statutory Declaration

Jalbiidandar, Sambuunyam 15350062136168

Last Name, First Name Student ID Number

I hereby affirm in lieu of an oath that I provided the submitted bachelor thesis

Study on the ball mill liner consumption in the Enrichment Factory of Erdenet Mining

I did not use any sources other than those stated. In case that the work is additionally submitted on a data medium, I declare that the written and the electronic form are completely identical. The work was not submitted in the same or similar form to any examination authority.

Place, Date Signature

Abstract

This research study primarily focuses on ball mill liner consumption in the Enrichment Factory of Erdenet Mining Corporation, a significant copper ore processor, processing 35 million tons annually. The corporation, established in 1974, exploits Asia's largest copper deposit and ranks as the world's fourth-largest copper mine. The Powder Concentrating Unit (WPU) at the Erdenet factory relies on nine ball mills to produce copper ore.

Given the critical role of ball mills in ore processing, the effective management and maintenance of these mills, specifically the consumption and replacement of mill liners, have immense implications on productivity, operational costs, and the overall efficiency of the processing plant. Therefore, this thesis aims to evaluate and estimate the lifecycle and replacement cycle of ball mill liners in the context of the Erdenet factory.

The research's primary objective is to propose methodologies for assessing the use, maintenance, and spare parts consumption of ball mill equipment, with a particular focus on the liners. It is expected that the results will not only provide a comprehensive understanding of the current liner consumption but also contribute to the development of strategies for optimized utilization, effective maintenance planning, and accurate prediction of spare parts demand. This thesis thereby contributes to the broader knowledge of equipment lifecycle management in the mining industry, with specific implications for large-scale copper mines such as the Erdenet Mining Corporation.

Acknowledgement

I would like to express my profound appreciation to the GMIT Engineering Faculty and Erdenet Mining Corporation for allowing me to implement my acquired knowledge to real-world problems. This study could not have been completed successfully without the participation and assistance of those around me, including supervisors, professors, and company engineers.

I am especially grateful to my supervisors, M.Sc. Batsengel Dashdorj and Prof. Dr. Sungchil Lee, for their direction, assistance, and perseverance in assisting me with this project.

Their consistent guidance, advice, and assistance throughout this research. I would also like to honor them for their insightful comments and suggestions.

I would like to express gratitude to Prof. Dr. Purevdorj B. He is my research advisor from the company, for his assistance and helpful ideas and suggestions. Additionally, he assisted us by providing data and information for research analysis. I would like to express my gratitude to all of my graduate colleagues and team members for their assistance and constructive criticism.

Last, but certainly not least, I would like to thank my family and friends for their patience and support throughout the completion of this bachelor's thesis. Their consistent guidance, advice, and assistance throughout this research.

Contents

Terminology

RoM	Run-of-Mine
Cu	Copper
WPU	Powder Concentrating Unit (WPU)
DEM	Discrete Element Method
ELAC	Electro-Acoustic
CCM	Continuous Charge Measurement
SL	The sensor lifter bar
BTU	Pulverizing Unit
SGU	Self-Grinding Unit
DU	Drying Unit
RMP	Repair Mechanics Plant
Grinding media	Steel balls and large rocks used to break the ore
Mill charge	Mixture of slurry and grinding media
Sensomag sentor	Device used to continuously measure both ball loading and slurry position within the running mill

Chapter 1: Introduction

Mineral processing is the crucial step in mining that separates precious minerals from ores. Searching ore deposits for natural minerals to isolate precious minerals. The collected ore is transported to the stockpile and then processed by primary crushers, such as cone crushers or jaw crushers. Floating feed with water and chemicals enriches it. The precious mineral adds its preferred chemical to the bubbles. Concentrating and filtering remove excess water from the enhanced product. Water, ore, and grinder components are employed in cylindrical grinding mills. Rods, balls, or even big ore chunks can be used as grinder pieces. Grinding impacts downstream mineral processing processes, including leaching and flotation (Sarpong Bismark Donkor, 2014).

All components of mining equipment are susceptible to abrasive and mechanical wear. Improving the wear resistance of materials, reducing repair costs, and reducing labor usage are still issues. It is essential to rework components that decrease production growth and boost efficiency. Today, the technology of reconditioning worn-out components is advancing rapidly in developed nations, where it competes with decades of experience and advanced technological capabilities. The fundamental conditions for replacement and repair are the restoration and reuse of used components, aggregates, and substandard machinery. According to studies conducted in a number of foreign nations, the restoration of auto components is 15-20 times less expensive than the production of new materials, and the initial investment is reduced by 5-10 times. The workgroup at the German Drum Excavator Company has effectively repaired a deteriorated tungsten carbide bucket with a partial additional bucket, resulting in a high level of spare parts economy. A preponderance of semi-automatic equipment will be installed in addition to the automatic equipment used to restore worn components. Automatic welding equipment is used in Germany, China, Russia, and Japan to repair composite structures in on-site repair divisions to increase production efficiency.

1.1 General background

1.1.1 Significant of copper

Copper is a chemical element with the symbol Cu and atomic number 29. It is a base metal that exhibits copper-red characteristics, tarnishes to brown, red, black, and green, and is conductive, malleable, resistant, and ductile in addition to being nonmagnetic and inherently non-hydrophobic [1]. Copper's crystal structure is isometric hexaoctahedral. This non-precious metal has a broad range of applications, including electrical wiring and motors, alloys, construction, art, and currency [2]. These diverse applications, according to experts [3], increase the global consumption of copper and place a significant strain on the global supply. Copper prices are regarded as one of the best indicators of economic health, as fluctuations in copper prices can signal an economic expansion or impending recession. Copper's current price is also influenced by the cost of extraction and transportation, The cost of extraction and transportation, as well as economic supply and demand, all have an impact on copper's current price [3]. economic supply, and demand [3].

Figure 1 Historical chart for the copper price, Markets Business Insider Exchange [4]

As shown in Figure 1, the price of copper has risen significantly since March 2020. In March of 2022, on the Markets Business Insider Exchange, the copper price reached $10,326.75 per ton. According to analysts, the increase was the result of falling copper inventories on key commodity exchanges. As copper prices have risen, copper mining companies' stocks have also risen [4].

1.1.2 Copper ore reserve

Copper ores are found as native copper, massive deposits, porphyry copper, and combined copper. They make up a large and geologically distinct group of ores. Copper is occasionally found in its unadulterated state, but it is typically found in combination with other minerals. Copper is the primary metal deposit in a number of the world's largest ore bodies, which also contain gold, molybdenum, zinc, or lead.

Copper concentrations in ore can range from 0.4% to more than 12%, and it is uniformly disseminated throughout the rock in porphyry copper deposits, which account for approximately 76% of all copper discovered. The copper minerals in the lower levels are sulfides, in which copper is bound to sulfur, while those on top of the deposits are oxides [5].

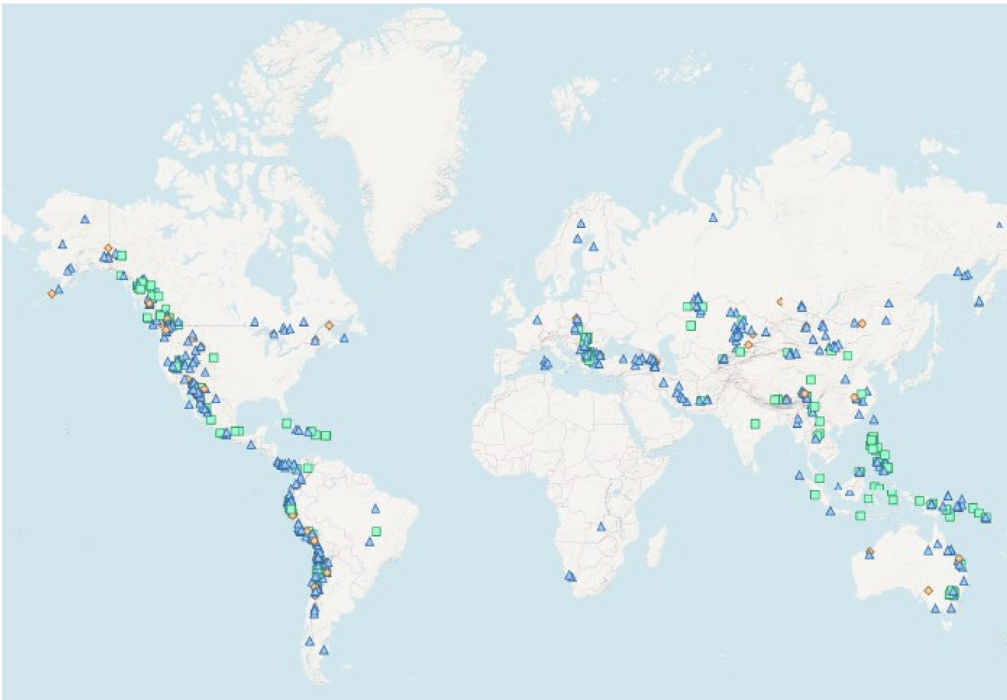


Figure 2 Mineralogical World distribution of porphyry copper deposits

Copper reserves on a global scale is estimated to be 870 million tons, while annual copper demand is 28 million tons. Copper resources are estimated to exceed 5000 million tons at present [6]. Figure 2 depicts the global distribution of porphyry copper and sediment-hosted copper deposits. This type of mineral deposit can be found on virtually every continent. Chile has the world's largest copper reserves with 200 million metric tons as of 2021, and its production is vital to its economy, accounting for 20% of its GDP [7]. Over 8000 occurrences in 1170 mines, 80 varieties of minerals and metals, and substantial reserves of copper, base metals, gold, coal, and uranium are among Mongolia's abundant mineral resources. In 2021, 57 million tons of copper reserves have been explored and confirmed.

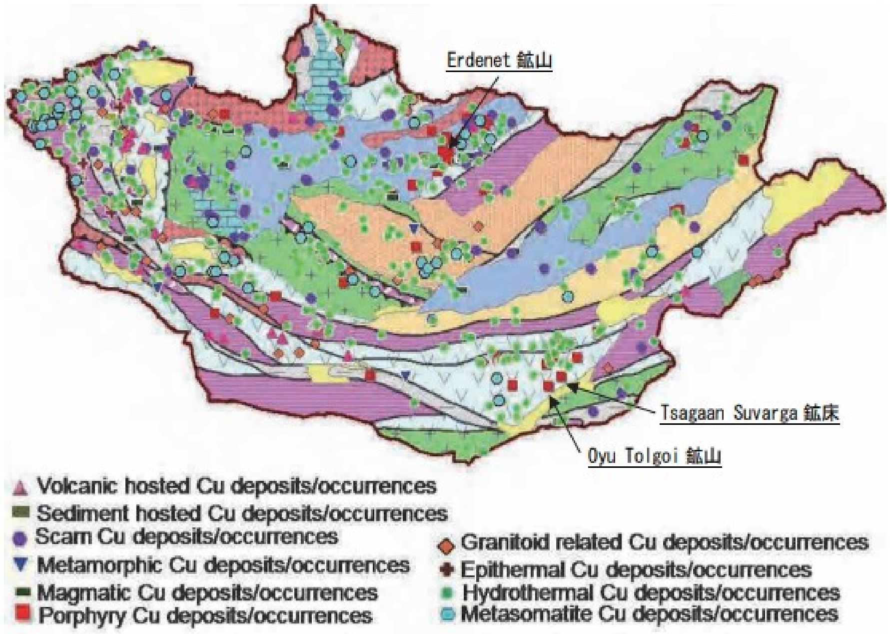


Figure 3 Outlined distribution of the copper deposits in Mongolia [8]

Mongolia possesses three copper deposit basins in its northern, central, and southern regions. Copper mineralization is associated with volcanic rocks and is classified according to the age of the mineralization and the rocks. The locations of porphyry deposits in the northern and southern regions of Mongolia, including Erdenetiin-Ovoo, Saran-Uul, Oyu-Tolgoi, and Tsagaan-Suvarga, etc. are indicated by red marks in Figure 1 [8].

1.2 Problem Statement

Damage to the mill should primarily be measured in various ways. However, problems have arisen in their practical implementation. Methods for estimating the level of injury are a well-known technique that is employed quite a little.

the present state of the art on attempts to measure the ball function has focused on especially gathering empirical data (malfunctioning amiss, and mill weight) in running mills, and measurements obtained from the process and process models are used.

1. Erdenet Mining has the capacity to crush several tons of ore per year and uses several mills.
2. The cost of damage and repair of those mills is huge. Among them, what is the damage percentage of the lining of the mill and at what cost is it repaired and replaced.

3. Instead of buying expensive spare parts from abroad, it is important for the factory to make the lining itself.

Due to the above causes and effects, this research was conducted in order to reduce production costs and improve efficiency.

1.3 The Objective of the Research

Currently, the Erdenet Mining Corporation processes 35 million tons of copper ore annually to create a copper concentrate. The city was founded in 1974 to exploit Asia's greatest copper mineral deposit and is the world's fourth-largest copper mine. There are nine ball mills that are used to produce copper ore in the Powder Concentrating Unit (WPU) of the Erdenet factory. The purpose of this thesis is to estimate the ball mill liners' life cycle and replacement cycle.

Chapter 2: Literature Review

Comminution, often known as particle size reduction, is an important feature of mineral processing and cement manufacturing. Grinding is the final stage of comminution in which tiny particles are broken down into even smaller ones in order to improve their chemical and physical qualities. Tumbling mills, which are revolving cylindrical drums filled with feed material and grinding medium, are a key category of grinding equipment. The general goals of grinding are to optimize mill throughput while maintaining the appropriate reduction ratio while reducing operational expenses. Grinding, on the other hand, is not only extremely energy-intensive but also quite aggressive in terms of wear. The smallest improvement in liner design can result in a major competitive advantage. The surface material of the liner is gradually worn away, and its form changes as a result of collisions between the balls, the ore, and the liner. In addition, after tens of thousands of hours, material loss increases due to wear, and the protective function of the liner is gradually lost. Advancing a liner with a uniform wear distribution and low wear rates reduces the expense of regular relining while also avoiding output losses during mill downtime. When designing a liner, not only the initial shape of the liner but also wear-related changes in shape over time should be considered. Due to the harsh factory environment and relatively long liner life, optimizing and testing traditional liner designs is a rigorous and time-consuming process. In particular, recent developments in computer technology have made it possible to simulate the motion of a mill ball in a reasonable amount of time using the discrete element method (DEM) on almost any personal computer.

A ball mill is a sort of grinding equipment that is utilized to finely grind materials for use in mineral beneficiation processes, paints, pyrotechnics, ceramics, and selective laser sintering. Ball mills work according to the principles of impact and abrasion.

The size of the balls and the workpiece are placed in a rotating container called a mill. Ball mills are widely used in the production of cement, silicates, refractories, fertilizers, glass ceramics, and other materials and can be used for both dry and wet grinding.

2.1 Comminution

Comminution is an essential part of mineral processing and production. It generally begins with the use of explosives to remove rocks from their natural beds. Following the blasting of the rock, huge particles are crushed. Primary and secondary crushers are used in the mining sector to compress or impact ore against solid surfaces. Primary crushers, such as jaw and gyratory crushers, are heavy-duty machines that reduce ore to a size that can be transported and fed to secondary crushers. Secondary crushers, such as cone crushers and hammer mills, are then used to further reduce the size of the rocks so that they may be ground. Target throughput and rock hardness are two factors that affect the kind and size of crusher to choose. Abrasion and impact are used to grind the ore particles to sizes ranging from 5-250 mm to 40-300 mm. As a result, the most energy-intensive step in mineral processing or cement production is grinding. For example, producing one ton of product consumes around 110 kWh of electrical energy [9].

2.2 Structure of ball mill

Ball mills are grinding devices that employ metal balls with diameters ranging from 10 to 150 mm and weights varying from 1 g to 4 kg as a grinding medium. Tumbling mills are devices that generally measure approximately 4 m in diameter and consume 5 to 10 MW of power (Figure 4). Their length-to-diameter ratio ranges from one to one and a half. Tube mills, on the other hand, are ball mills that generally have a length-to-diameter ratio of 3 to 5.

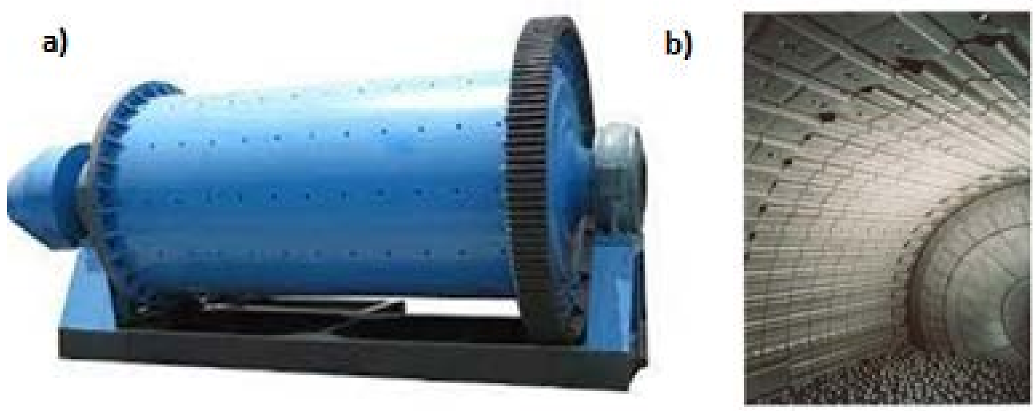


Figure 4 (a) Ball Mill (b) Inside appearance of ball mill

The mill shell is the cylindrical drum of a ball mill that revolves at a constant speed around its horizontal axis. It is supported at both ends by oil-lubricated or roller-type bearings. The cylindrical drum in tube mills is frequently divided into many sections with decreasing bulk material sizes. This method is extensively used in the mineral industry for clinker grinding [10].

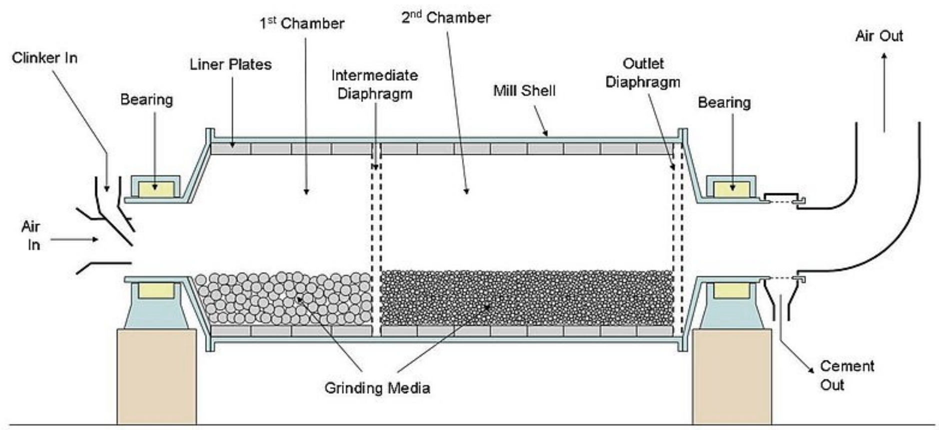


Figure 5 Tube mill with two chabers for clinker grinding

Because of the extremely hostile impact and abrasion environment within the mill, liners are used to protect it as shown in Figure 4 (a).

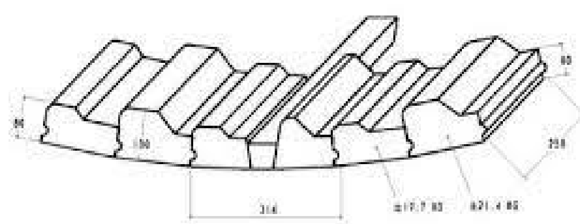


Figure 6 Boltless liner row with main dimensions. This image depicts the vaulted liner keystone, the sole liner plate fastened to the mill shell. mm length

Mill liners have replaceable metal or rubber working faces. Two types of liners exist. Conical or flat headliners serve to protect the cylindrical mill's lateral end walls. Shell liners are arched. plates joined to the mill shell by bolts, the vault effect (boltless lining), or direct bonding to the inner surface for rubber linings. Figure 6 shows how liner plates are arranged into rows around the mill. Axial rows create the shell liner.

Typically, chromium, manganese, molybdenum, and nickel alloys are utilized to manufacture liner plates. These alloys have the benefit of being fairly hard and resistant to wear, but as their hardness goes up, they become more brittle. Their counterparts are rubber liners, which are especially well-suited to regular impacts because of their high elasticity, i.e., they flex readily and return to their original shape when the forces are eliminated. Rubber-steel composites and magnetic liners with thick rubber layers that are themselves protected by the attracted mill charge are also available [11].

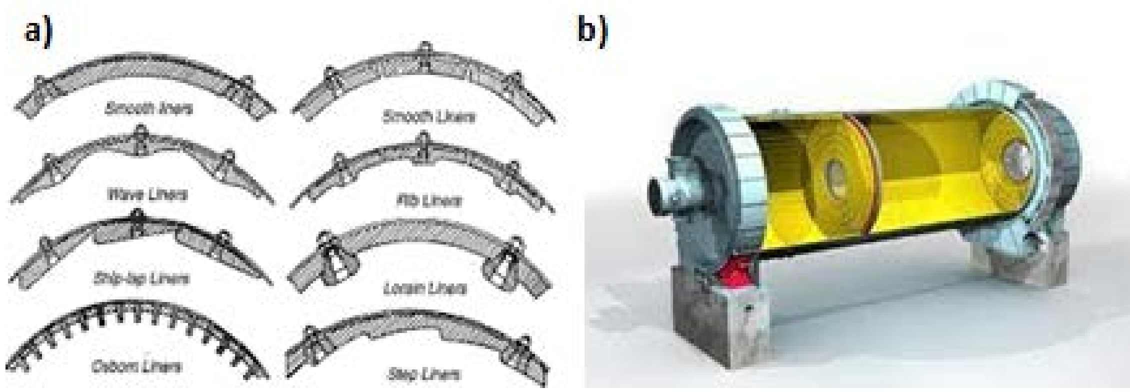


Figure 7 (a) Liner profile (b) Ball mill

The second principal role of the liner, in addition to protecting the mill shell, is to transmit energy from the mill's rotating motion to the charge, which eventually results in the grinding of the feed material. To encourage the most advantageous motion of the charge, the liners have varying profiles as shown in Figure 7 (a), which should improve the size reduction by adding impact crushing and improved abrasion efficiency to the comminution process via their lifting action. Combining centrifugal and frictional forces to move the charge to a higher location in the mill is the exact definition of lifting. At some point, gravity pulls the charge down, and when it hits itself, the grinding speed increases. A lifter is the distinctive portion of the liner profile that aids in the lifting of the charge. For a lengthy liner life, the liner profile must be preserved, along with the minimum liner thickness for mill shell protection. Liner design requires wearing profile confirmation and improvement.

2.3 Types of Tumbling Mills

Various applications exist for tumbling mills based on their operating principles. There are four distinct mills based on the varieties of grinding media used for material comminution. This includes autogenous (SAG) and semi-autogenous (SAG) mills, ball mills, and rod mills. The design of modern tumbling mills has improved in terms of mechanical performance and dependability, but they are immensely inefficient in terms of energy consumption. This is because, according to Usman and Husni, the majority of forces involved in fracturing ore in grinding mills come from repetitive and random impact, which breaks both liberated and unliberated particles [11].

.2.3.1 Autogenous (AG) mills

In autogenous mills, the only input is the ore itself, which can significantly alter its dimensions. Inside a mill, large stone slabs and tiny crushed stone fragments move around and collide with one another. Otherwise, it employs the action of ore on ore to reduce the scale of the ore, resulting in the creation of smaller rock materials. When the particles are suitably small, they pass through the mill's discharge aperture, while new ore materials are continuously added. However, a completely autogenous mill's weakness is that it generates a relatively significant quantity of critical-size rock material.

2.3.2 Semi-Autogenous (SAG) Mills

In semi-autogenous mills, the input consists of the ore itself as well as water and steel pellets, which accelerate the grinding process. The specific gravity of steel spheres should be two to three times greater than the average specific gravity of all other materials. Typically, the spheres are composed of high-strength iron and steel. Therefore, it is not a good idea to add an excessive quantity of balls to the mill, as they account for a significant component of grinding costs.

In addition, if there are too many spheres in a well-functioning mill, they wastefully increase motor power. Typically, a semi-autogenous mill is used for primary grinding. The percentage of steel pellets utilized ranges from 6 to 18 percent [12], depending on the ore's behavior. The SAG mill has a short length and a sizable diameter. SAG is one of the most commonly employed comminution techniques.

The plant consists of large chunks of rock and water that are fed into a grinding mill with steel spheres that rotate at a fraction of their critical speed. Before being cascaded, the ball adheres to the mill's walls in order to contain the sediment. a given angle, resulting in ore fragmentation through impact [13].

2.3.3 Ball Mill

The ball mill is typically used for secondary milling. Steel pellets make up between 30 and 40 percent of the mill's total volume, which can range from 30 to 40 percent. In this case, the projectile is doing the polishing. The input aggregate size for the ball mill is approximately 1 millimeter, and the output is a powder-like substance. In comparison to the SAG mill, the ball mill has a smaller diameter and a longer length [14].

2.3.4 Rod Mill

Rod mills grind materials into a fine powder used in mining, metallurgy, and building. They grind materials in a spinning drum using rods like ball mills. Rod mills employ steel, ceramic, and rubber rods. Application and mill size determine rod length and diameter.

Rod mills grind through drum rotation and rod movement. The rods tumble and break up the material being ground while the drum spins. By rolling and sliding, the rods crush particles even smaller. Rod mills grind coal, limestone, iron ore, and copper ore. They also process gold and silver.

2.4 Charge motion

Figure 8 depicts ball charge velocity, zones, and locations. Due to spin and friction, the increasing liner profile lifts the charge. When the force of gravity is stronger than the forces of centrifugation and friction, the charge cascades or cataracts down the surface of a free particle. At lower rotational speeds, the charge cascades down, i.e., the balls roll down, but at higher speeds, the balls fly down and collide with other balls and feed material at the impact zone. This cataracting action results in comminution via impact, whereas cascading balls diminish the size of the material through abrasion.

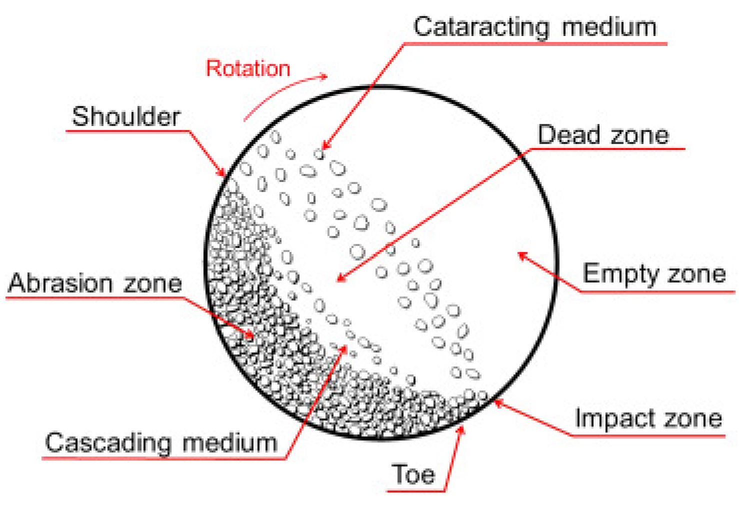


Figure 8 Motion of the ball charge in a ball mill [15]

Shoulder is where the charge peaks. This point is easily defined at low rotation speeds, but at higher speeds, cataracting charge motion makes it harder to distinguish. Hence, establishes shoulder position limits. The charge peaks and particles near the liner begin to diverge at these limits. Its lower limit is where the charge free surface meets the mill liner, and its higher limit is where the maximum concentration of cataracting particles hits the liner. These zones are solely used to qualitatively distinguish mill zones and simplify mill charge motion description. The lower toe limit is not usually in the impact zone for liner wear. For low mill filling or poorly constructed liner profiles, the mill charge, especially cataracting balls, may directly strike the liner at high rotating speeds, accelerating liner wear. Because the liner receives the maximum impact energy instead of the toe, milling efficiency may drop [16].

2.5 Characteristic parameters

There are 2 types of mill operation including the percentage of critical speed and the filling ratio. The percentage of critical speed: This is the rotational speed of the mill at which the centrifugal force on the interior surface of the mill is equal to the gravitational force. Ball mills have a critical speed of 70%–80%, with higher values resulting in more efficient grinding. The precise proportion depends on the mill's size and form, the grinding media's size and shape, and the material being processed. Typically, it is expressed as a percentage of the critical velocity. If the mill rotates faster than the critical speed, the grinding media within the mill will adhere to the interior wall, and the mill will not effectively pulverize the material. When centrifugal force equals gravity on a ball, the critical speed is reached [18]:

$$\frac{mv^2}{R} = mg$$

The linear velocity v of a ball of mass m is a function of the mill's rotation speed N in [rpm] and the radius to the center of rotation $R = \frac{D-d}{2}$ where D and d are the diameter of mill and ball.

$$v = \frac{2\pi NR}{60}$$

- R is the radius to the center of rotation
- D is the diameter of the mill
- d is the diameter of the ball
- N is the rotation speed of the mill in revolutions per minute (RPM)

And PI is the mathematical constant pi (approximately 3.14159)

Drum frequency is the ratio of mill drum critical speed to actual speed. Proxy critical rotation is the drum's speed at which the ball's inertia equals its gravity. Hence, tiny grinding media at the highest point are in dynamic equilibrium.

Formula for critical speed,N_C:

$$N_C = \frac{42.3}{\sqrt{D}} \ [rpm]$$

where:

- D – inside diameter of ball mill drum, m.

Fill ratio: If no entire ball charge distribution is available, the mill operation is described by the ball filling ratio and the percentage of critical speed. Ball charge categories are based on diameter. Each group's diameter interval enables for mean diameter calculation. Given the ball material density and ball group mass, one may calculate the number of balls per mean diameter. Even if the balls are ground, their size distribution is maintained by introducing fresh ones. Consequently, the mill's ball size distribution remains constant. The filling ratio may estimate the mill's ball count without this specific knowledge. The filling ratio is the percentage of the mill's volume that is filled with balls and interstices without feed material [19].

The mill's volume is determined by the liner profile's mean diameter and length. A clinker grinding tube mill's initial chamber filling ratio is typically 20–40%.

2.6 Discrete Element Method

Understanding and quantifying the mill charge motion and its interaction with the mill liner is necessary to forecast liner shape development due to wear. The discrete element method (DEM) is most promising in this subject. Thus, we will first explain the concept and then apply it to ball mill simulation.

Since DEMs are widely used for studying particle flow, simulating the grinding process using them can help researchers learn more about the grinding mechanism and come to more informed conclusions and forecasts. The analysis, which takes into account both theoretical and experimental data on the combined motion of the falling and dropping steel balls, demonstrates how different grinding needs can be satisfied by selecting the proper rotating speed and ball charge ratio.

Cundall and Strack (1979) appear to be the first to propose DEM for rock mechanics analysis. Mishra and Rajamani et al. (1992, 1994) utilized the DEM to examine charge movement in the tumbling mill. (Moys et al., 1994) DEM has been extensively used to extract load shape features and analyze charge motion in 2D and 3D for the prediction of charge shape and charging trajectory in the industrial mill. It was also used to predict the charge motion in rotary mills as well as the power, segregation, and attrition rates in ball mills. DEM usage is costly due to associated computing expenses. Most DEM codes for tumbling mills do not account for even partial content fragmentation, making it challenging to estimate the effect of charge characteristics on mill performance. This has generated interest in the study of sensor technology.

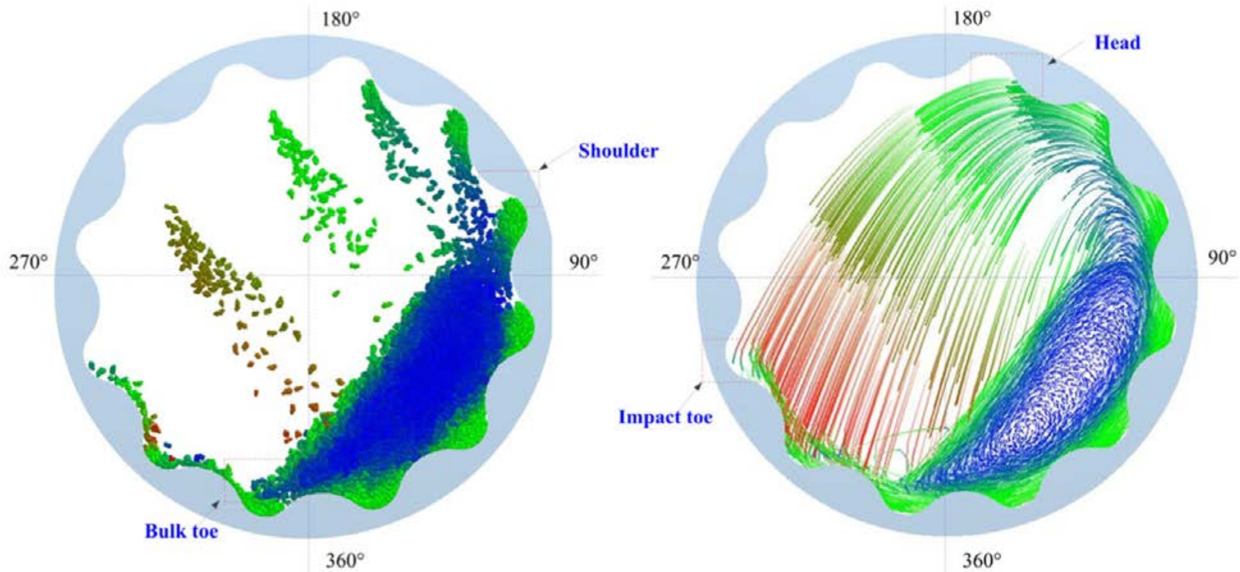


Figure 9 Schematic representation of trajectory depicts four important feature locations [17]

The affected toe, bulk toe, shoulder, and head areas were determined by seeing the charge form and streak pattern. Figure 9 shows how DEM particle visualization was utilized to estimate the bulk toe and shoulder positions. Streak patterns, as shown in Figure 2.5, to calculate impact toe and head positions. Tracing each particle's motion over 0.2s creates a streak. The streak patterns reflect the charge's velocity, while the particles' current position is displayed in a normal representation. This helps them detect the cataracting stream and bulk form.

2.7 Liner Wear for ball mill

Wear decreases ball mill liner efficiency. The liner thickness lowers, reducing mill shell protection. However, the liner profile changes, losing its capacity to elevate the charge to a certain height.

Wear determines the liner's lifespan, which has a considerable economic impact owing to the direct relining cost, increasing output losses, and mill downtime. At 300 tons/hour production, downtime must be minimized.

Liner wear in ball mills is caused by interactions between the balls, feed material, and liner, hence charge motion inside the mill must be modeled using the discrete element approach. This model should anticipate the ball charge's kinematic, dynamic, and energetic behavior, including wear, normal force, impact velocity, sliding distance, etc.

Material wear models relate ball charge simulation mechanical data to liner profile transformation to predict liner wear. This change is two-stage. First, charge motion must identify local material loss. Liner profile geometry is revised once material loss is determined.

This section reviews charge motion simulation, wear modeling, and geometry modification methodologies for ball mill liner wear prediction. These three aspects will be described generally. In the literature's primary liner wear simulation case studies, certain principles will be addressed [18] [19].

Equation 1 Linear profile wear using material attributes

$$\dot{m_{lin}} = \rho_{st}\frac{tan(\theta)}{\pi H_R}N_t V_{surf}$$

where

m_{lin}	= liner wear,	ρ_{st}	= metal density,
θ	= abrasion factor of material,	H_R	= metal hardness,
N_t	= total normal force,	V_{surf}	= surface slippage velocity.

Wear simulation focuses on liner forces. These pressures enter Equation 1, which computes liner profile wear using material attributes. Figure 10 (a) shows the author discretizing the liner in one dimension to calculate wear at specific spots [20].

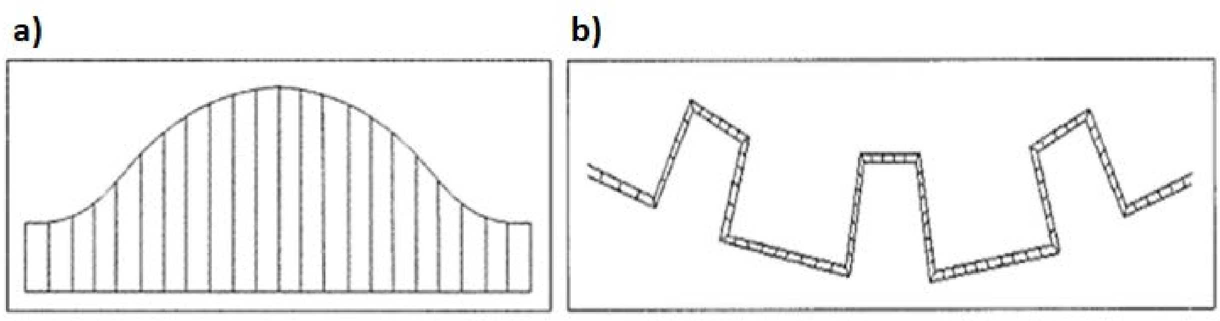


Figure 10 (a) Radziszewski's technique for simulating Liner Wear [21] (b) Cleary's technique for simulating Liner Wear [21]

Author-developed charge motion is utilized to calculate liner wear. Along the surface of the liners, data for calculating wear is gathered. The information consists of the normal, tangential, and total boundary forces operating on the liners. As depicted in Figure 10 (b), each liner is subdivided into sequences of equal-sized segments for data collection on the liner surface. Wear predictions are made by feeding the data acquired in the object containers into Finnie's wear model [46], thereby computing the Liner Wear profile.

2.8 Technologies for measuring load behavior in tumbling mills

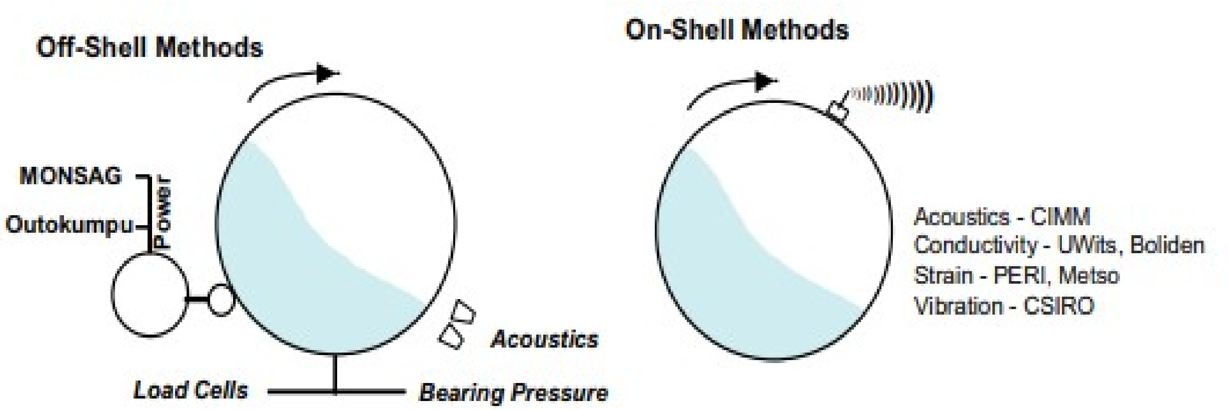


Figure 11 Methods of load measurement [21]

Tumbling mills waste energy by impacting particles without breaking them. Due to the difficulty of balancing feed replenishment of large ore particles with charge consumption, autogenous (AG) and semi-autogenous (SAG) mills often operate unstably. This has increased interest in accurate and direct mill load and charge behavior measurements. Some parameters that affect grinding efficiency are hard to measure. Intermittent in-situ readings of particular parameters are typically inaccurate and take a long time to feed the control system. Mill optimization requires understanding charge motion [22]. Charge motion causes ore particle fracture and liner/ball media wear. Thus, the control system must receive precise, real-time charge data.

Load measurement has been done off shell and on shell, c.f... Many plants measure mill feed and discharge bearing back-pressure. It indicates charge weight and filling level. Bradken Mineral uses bearing pressure, power draw, and mill speed to compute charge load weight. One system deployed on a 28ft SAG-mill at Noranda Mine in Brunswick showed that mill load may be related to bearing pressure if mill liner wear and mill drive system wear are included [23]. Pressure fluctuates, causing sensor drift.

Since bearing pressure is related to mill weight, ball charge and lining wear affect the signal. Thus, robust calibration is difficult. Bearing pressure can regulate SAG load despite these issues. Load cells under SAG mills can reduce bearing pressure. To detect mill load when running, sensors must be installed beneath all weight-bearing parts, such as pinions.

Single microphones [Watson et al., 1985] associated sound power with pulp viscosity, whereas arrays of microphones (Jaspan et al., 1986) detected mill charge toe position variations. Koivistoinen et al. (1989) employed high-frequency power draw sampling to estimate mill loading. Power draw phase shifts with charge toe location. Järvinen (2004) found results equivalent to invasive approaches. In Chile, CIMM's MONSAG (monitoring SAG mills) equipment uses power consumption and a complicated signal processing method to measure torque, which is connected with volumetric filling. The technology detects mill under and overfilling wells. Pontt (2004) validated the system on a 15 kHp SAG mill and found a 3.2% improvement in throughput and a better knowledge of mill operation. Apelt et al. (2001) developed a mill power draw model to forecast total filling and ball charge levels using a similar strategy.

Other measurements use a mill shell device. Electro-mechanical difficulties from service needs have slowed development of these gadgets. Since these systems can directly infer load type, this approach is appealing. Two lifter-mounted probes can assess mill conductivity (Moys, 1988, Vermeulen et al., 1988). This approach yields satisfactory findings, although probe wear causes drift. Berggren et al. (2000) created a comparable technique to determine load toe and shoulder position during one of their procedures.

Acoustic devices like CIMM's ELAC (Electro-Acoustic) indicate the load's toe and shoulder without touch. Geometrical calculations estimate load. A more advanced non-contact acoustical technique employing Fourier transformation to relate observed signal to process parameters is being studied (Pax, 2001). Simple equipment outside the mill eliminates maintenance stops for component interchange.

Accelerometers on the mill shell measure SAG mill surface vibrations in the AMIRA project (Campbell et al., 2001). The vibration signal indicates charge mobility and warns of poor operating conditions. Zeng and Forssberg (1994) placed accelerometers on both mill trunnion bearings. They demonstrated that vibration signal measurement can monitor ball grinding parameters.

Soft-sensor load estimation is a category unto itself. This usually comprises field observations and phenomenological models of the mill's mass balance. The more field measurements the soft-sensor has, the better it can predict ore grindability on-line.

A University of Utah soft sensor and Herbst and Pate (1996) ComMINSens system are model-based techniques. On a SAG mill, the latter system predicts mill performance within 2% and can maximize throughput for different ore qualities.

Because DEM modeling can be used with lifter force measurement techniques (Herbst et al., 1988), they are gaining popularity. Process Engineering Resources Inc. (PERI) sells CVM, which infers lifter normal forces from strain relaxation in an instrumented lifter washer or bolt. Unless the lifter is in command, these are inconsequential. Kolacz (1997) measured mill load with a piezoelectric strain transducer. Ball charge load directly affects mill shell strain. This work uses a rubber lifter-embedded strain gauge sensor. Metso Minerals' CCM (Continuous Charge Measurement) system includes the sensor (Dupont et al., 2001).

2.8.1 Conductivity Probe Technology

Two electrodes anode and cathode make up the conductivity probe. Voltage over the probe evaluates fluid conductivity. Voltage forces negative ions to the anode and positive ions to the cathode. Ion motions indicate conductivity. Mineral industry conductivity probes measure slurry density and mill load shoulder position.

Moys (1985), Herbst (1988), and Gabrdi (1998) pioneered sensors, probe conductivity, and grinding mill control. Conductivity measurements well characterize load-behavior, which is heavily impacted by slurry rheology, according to Moys and Montini (1987).

Moys said A laboratory mill probe was used to study mill load effects on toe and shoulder postures. The sensor face was parallel to the rotating milling axis and placed into the mill's liner bolts. The epoxy covering insulated the probe from the liner and shell to prevent electrical current loss. Load behavior was evaluated for rotational speed and volumetric filling. Figure 12 displays a built-in conductivity test.

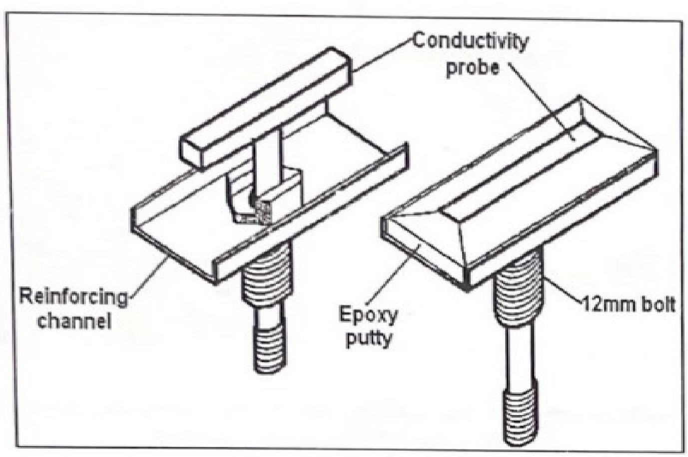


Figure 12 Built-in conductivity test

2.8.2 Strain Gauge Sensors

Recently developed electronic measuring system (Persson, 1994-1999). If the mill has a rubber or rubber-metal lining, or if a sensor-equipped rubber lifter bar can be installed in a steel-lined mill, it is designed for continuous measurement of the charge volume and angle of repose.

The apparatus consists of three primary components: the sensor, the telemetry system, and the data analysis and display computer. As the number of deflections of the sensor spring exceeds the normal fatigue limit, which is typically on the order of 10 million, the sensor is the most susceptible component. In addition, the sensor is exposed to moisture/water at temperatures spanning from 30 to 60 degrees Celsius, as well as periods of increased tension during each revolution. Consequently, the system's components are meticulously constructed and assembled.

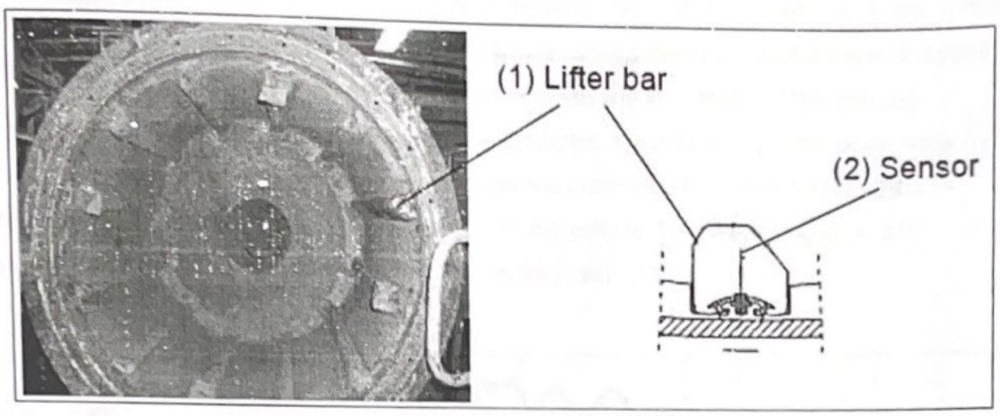


Figure 13 Pilot mill showing the lifter bars where one of them has a strain gauge sensor installed, (1) the right part shows the lifter (2) with a strain gauge [21].

Figure 13 depicts a simplified perspective of the sensor. A number of lifters are located within the mill's housing. One of these lifters (1) has a leaf spring whose deflection is measured by a strain gauge (2). As the mill rotates and the sensor-equipped lifter descends into the charge, the force exerted on the lifter increases, causing it to deflect. This deflection is converted into an electrical signal by a strain gauge attached to the leaf spring.

The signal is then amplified, filtered, and transformed into a pulse with a modulated HF-signal in the transceiver, which is then transmitted by the antenna wired around the mill to the receiver located near to the mill, cf. Figure 14. The transceiver is powered by a generator operated by a pendulum and mounted on the mill's end, or in the case of the prototype mill, by a battery cell mounted on the mill shell. A trigger pulse is activated once for every revolution on the receiver. This allows the system to determine when a fresh revolution begins. Finally, the signal is transmitted via cable to the measurement computer, where it is calculated, analyzed, and displayed. The frequency at which the computer's A/D converter acquires data is 100 Hz. The computer stores all the data for further processing. Pilot and full-scale ball mills have one sensor in the middle. Figure 14 shows AG mill sensor placement.

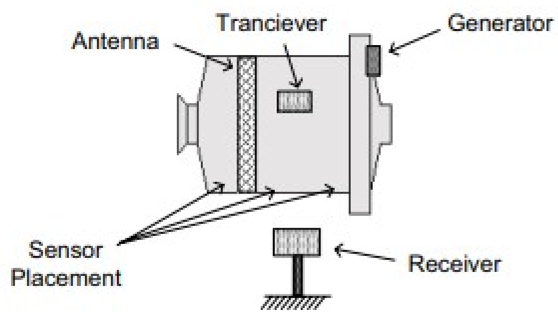


Figure 14 Overview of the mill with its mounted system components [21].

2.8.3 Strain-gauge signal features

Figure 2.8.3 depicts a typical deflection profile of the sensor signal and the corresponding graphical representation of a simulation of a mill. Figure 15 depicts significant dynamic events that occurred during the passage of the sensor-equipped lifter bar beneath the mill charge.

1. The sensor lifter bar (SL) is still in the air
2. The SL hits the surface of the slurry
3. The SL starts to get submerged in the slurry
4. The SL hits the ball charge and starts to get submerged in the charge (T4)
5. The SL starts to bend forward due to turbulence in the toe area
6. The SL grips the ball charge again
7. The SL is at peak bending
8. The SL has gradually decreased the bending and is at take-off position
9. The SL is leaving the ball charge and starts slowly rise to an upright position (T9)

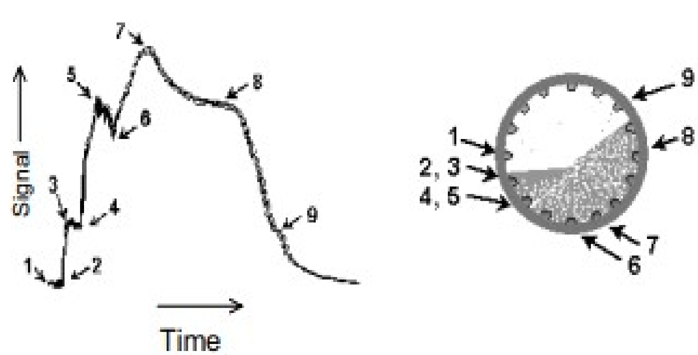


Figure 15 CCM raw signal, showing the bending of a rubber lifter during the passage of the charge [21].

Calculating fractional filling J and dynamic angle of repose α radians from a CCM system's raw signal is relatively simple, given that the change in force acting on the lifter is proportional to both (J, α) of the mill charge. Equations (1) and (2) provide a straightforward method for estimating these parameters, where N is the mill speed (rps) and T is the time (s) when the lifter enters and exits the charge.

$$J = (T_9 - T_4)N - \frac{(\sin 2\pi(T_9 - T_4)N)}{2}$$

$$\alpha = \pi(T_9 + T_4)N - \frac{\pi}{2}$$

The angle of the toe and shoulder can also be derived from the CCM unprocessed signal. One method is to examine the signal's derivative and select T4 as the toe angle and T9 as the shoulder angle based on the signal's derivative. Metso CCM employs a proprietary algorithm to calculate toe and shoulder angles and mill load volume. There is no standard method for expressing toe and shoulder angles. In this study, the horizontal line serves as the reference for the measurement system applied to ball mill applications. The corresponding reference for the AG mill is the vertical line, cf. Figure 16

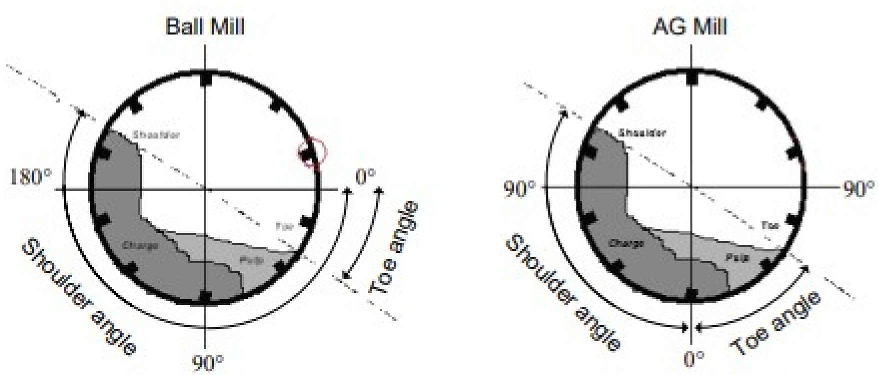


Figure 16 Angular reference for the Ball Mills (left) is the horizontal line and correspondingly for the AG Mill (right) is the vertical line.

Chapter 3 Methodology

3.1 Introduction to Erdenet Mining Corporation

Erdenet Mining Corporation is a mining corporation headquartered in Erdenet, Mongolia. The city was established in 1974 to exploit Asia's largest copper mineral deposit and is the fourth-largest copper mine in the world. The Erdenet Mining Corporation is a Mongolian-Russian joint venture that generates the majority of Mongolia's foreign exchange income. Erdenet annually extracts 22.23 million tons of ore, producing 126,700 tons of copper and 1954 tons of molybdenum. The mine contributes 13.5% of Mongolia's GDP and 7% of the country's tax revenue. The mine employs approximately 8,000 people [24].

3.1.1. Introduction of BTU and WPU of the Concentrating Mining Corporation

The "Erdenet Mining" SOE Concentration Plant consists of four principal workshops. It is comprised of the Pulverizing Unit (BTU), the Powder Concentrating Unit (WPU), the Self-Grinding Unit (SGU), and the Drying Unit (DU). Beginning with the reception of ore in BTU and SGU bunkers, the technological procedure concludes with the shipment of concentrates to clients.

The large crushing portion of the concentrator is filled from the open-pit mine by BeLA3 75131 and BeLA3-75145 dump trucks with a capacity of 120 to 130 tons, and unloaded into two hoppers for receiving ore from the KKD1200/130 GRSH type large crusher. The crushers can operate alternately or concurrently. During the working period of the level, the total cargo delivered by two mixers to the No. 3 conveyor should not exceed 3,200 tons per hour. These structures and facilities are included in the BTU:

- A large pulverizing plant coupled with a mineral extraction plant
- Amplification and transmission station warehouse
- large crusher ore pile warehouse
- medium and small crusher warehouse
- Shredded ore warehouse
- Belt conveyor galleries 1, 2, 3, 4,5, 6, 7, 8, 9, 11, 17
- Galleries accessible from the administration building

The BTU equipment is shown in Figure 17. The crusher controls a light signal that is near the silo and controls the ore discharge of self-unloading vehicles. In the event that ore and slag larger than the crusher's capacity are present in the ore extraction area, they will be removed using an electric excavator equipped with a crusher and a container positioned in the center of the crusher. During an emergency crusher closure, excavators will be used to remove the metal and ore that have blocked the crusher. Before the pulverizer is a stationary ingot sieve with a 150-mm distance between the rods. The greatest dimension of ore extracted from the open pit does not exceed one meter.

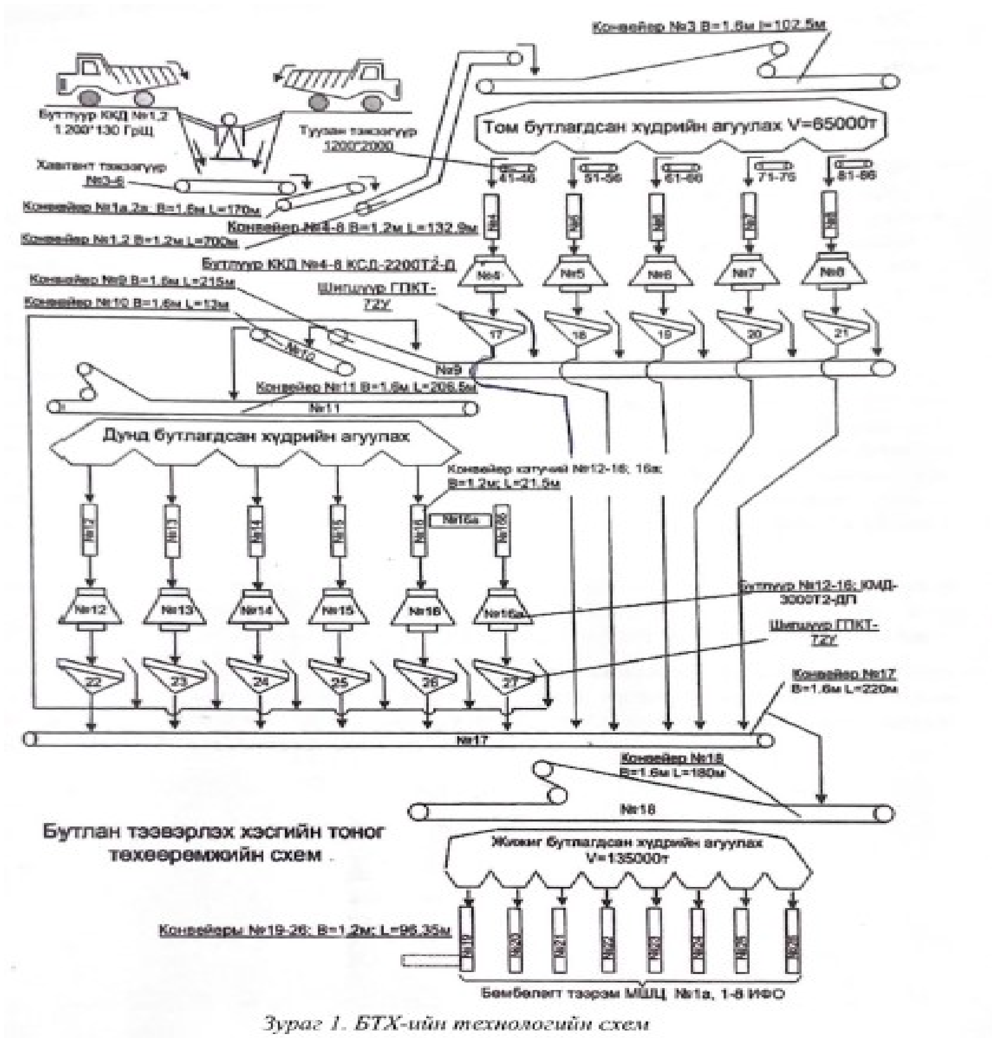


Figure 17 WPU’s equipment system

Crushed ore with 250 mm aggregates is fed to Japanese-made parallel belt conveyors No. 1a and No. 2a, which are 170 meters long and 1,600 mm wide by four 9.9-meter-long, 2,400-mm-gauge steel plate feeders. Ore is drawn on No. 1a and No. 2a belt conveyors with a metal separator (MFQ11801-BGP) for extracting the best metal from the incoming ore, and the reliability of the belt conveyor has been increased by using No. 1a and No. 2a belt conveyors with a length of 700 meters and a width of 1200 mm under the tensioning station. A 100/20 or 10-ton electric overhead crane with a 15.5-meter span is used for repair and technological work in the large crusher hull.

The No. 3 belt conveyor, which is 1600 mm wide and 102.5 m long and is located in the sizable ore warehouse, receives ore from the tightening station by way of the No. 1 and No. 2 belt conveyors. A distribution cart pours the crushed ore into the ore warehouse after it has passed through a sizable crusher on the No. 3 belt conveyor.

Each stage of the pulverizing process is designed to reduce the ore's particle size. For large crushing, mineral size is reduced to 200–250 mm; for medium crushing, 70 mm; and for tiny crushing, 15 mm or less. This demonstrates the relative nature of the distinctions between large, medium, and tiny.

3.1.2 The function of the section on milling and beneficiation

The purpose of the grinding and beneficiation section is to prepare the crushed ore for subsequent operations after beneficiation, based on the intended capacity of the plant, and to mill the minerals in the beneficiation products until they are entirely weakened. The combined mode (cascade-waterfall) employs a central discharge for the complete grinding of pulverized materials and intermediate products from the crushing transport section. The MSHTS-5.5x6.5 and MSHTS 3.2x4.5 ball grinders function. Large MSHC-5.5x6.5 mills are used for primary grinding, while MSHC 3.2x4.5 mills are utilized for final grinding. A counter-helix is positioned at the mill's outflow to return unground ore and steel ball fragments.

Figure 18 shows the equipment of the WPU.

WPU's primary machinery consists of nine, MISHTC-5.5x6.5 6 mills, six, MSHTC 3.2x4.5 3 mills, and six flotation plants. A hydrocyclone and 23 GRAT-1400 pumps are among the auxiliary equipment. The degree of drum filling, the density of the slurry leaving the mill, the amount of primary feed and the amount of aggregate, the number of rotating components and the amount of rotating load, the density of the hydrocyclone, the design and condition of the mill outlet, and the design and condition of the mill lining vary minimally in ball mills. It functions effectively by regulating and stabilizing it. 40-43% of the working volume of the wheel is the optimal loading level for a ball mill with a central discharge. The size and structure of pellets added to the mill are determined experimentally by considering parameters such as unground ore strength, total and largest grain size of primary ore, fractional composition, capacity, degree of grinding, physical and mechanical properties of grinding ore, and mode of full loading. During the grinding cycle, the quantity, totality, and density of the primary input should not deviate by more than 5 percent from the values specified on the technology card.

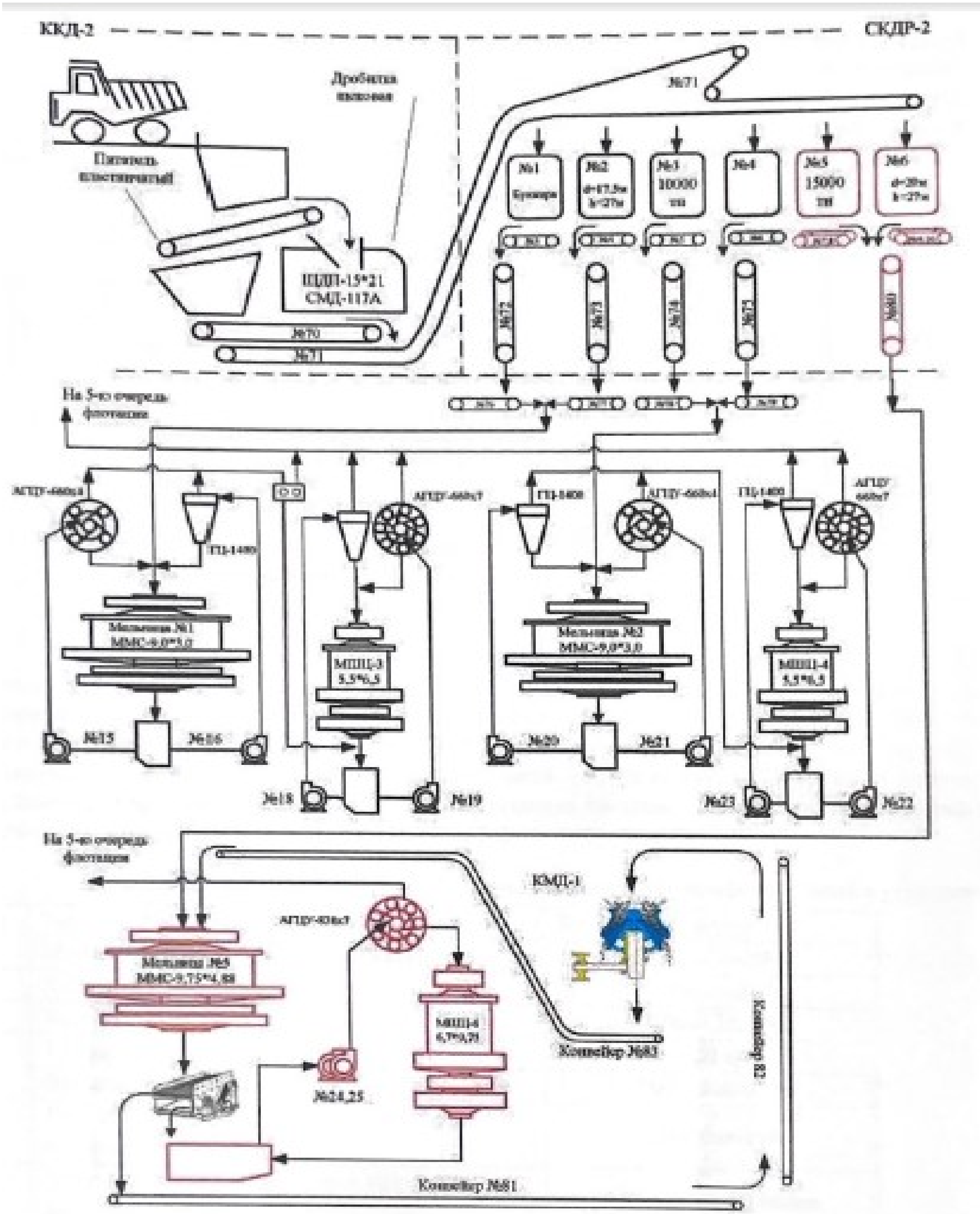


Figure 18 MHSTS mill's system

The ore that is not transported to the mills is conveyed by nine conveyors with designations No19 to No26. Each of these conveyors will have a series of six telescopes. Each telescope has six feeders, which are fed from the central mineral store. In a single mill, two hydro cyclones and two compressors operate simultaneously. Pumps and hydro cyclones in a closed grinding cycle will operate continuously and effectively based on the quality of the assembly, the protection of the working components, and the stability of the pressure.

3.2 Ball mill used in Erdenet Factory.

Figure 19 show the ball mill used in Erdenet Factory. The equipment used for the grinding process and the type of grinding body are classified as ball mills, rod mills, gravel mills, self-grinding, and semi-self-grinding mills. In the Powder Concentrating Unit (WPU), 140 m3 of MSHC 5.5x6.5 with a grinding capacity of 280-290 tons, 160 m3 of MSHC 5.8x6.9, and 3.2x4.5 m3 of MSHC 3.2x4.5 can be used. made by grinding.

Figure 19 Ball mill in Erdenet Factory

3.2.1 State of use of MSHTC mill

A total of 9 mills are used in WPU for MSHTC brand maschine. They are numbered as follows: No. 1, No. 1a, No. 2, No. 3, No. 4, No. 5, No. 6, No. 7, No. 8. Their position in relation to other equipment is shown in Figure 20.

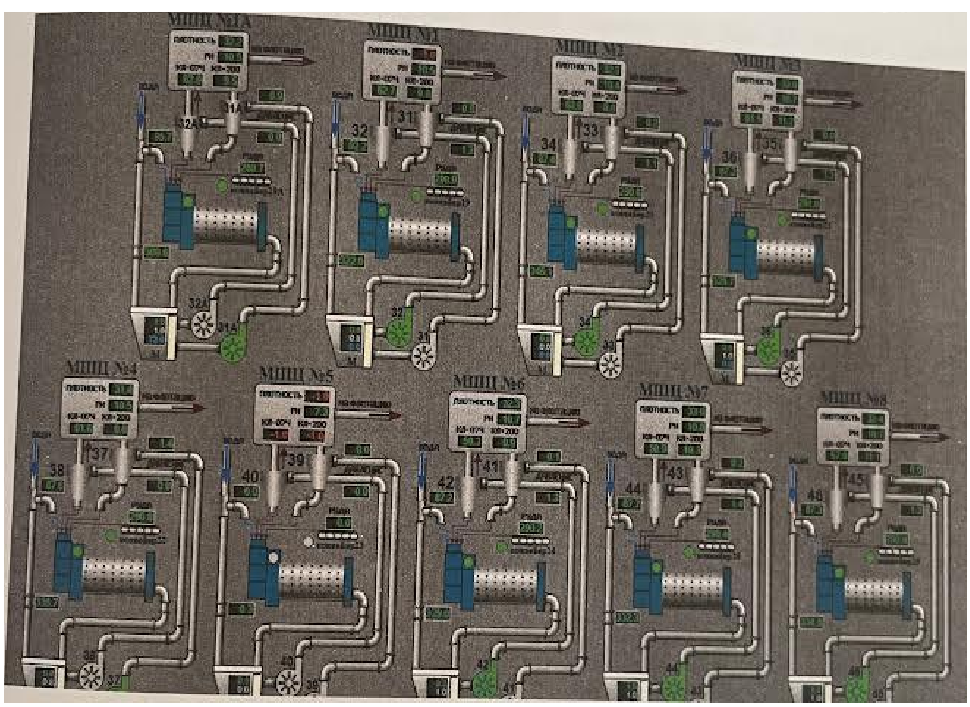


Figure 20 Mill system

Technical specifications of the MHC-5.5x6.5 mill:

1. Internal diameter of unarmored stage - 5500 mm
2. Drum length - 6500 mm
3. Normal working volume of drum - 144 m3
4. Drum loading mass-290 tons
5. Drum rotation frequency 13.69 revolutions/min
6. Width - 12400 mm
7. Length-28470 mm
8. Height-8800 mm
9. Electric motor power - 400 kW
10. The mass of the mill without an engine is 1054.3 tons.

The MSHTC mill is in charge of grinding minerals with steel particles. The drum, which is the primary component of the structure, consists of two drum sides, a device for receiving ore from the conveyor, a device for releasing pulverized ore, a gear mechanism, and an electric motor for transmitting rotation to the mill.

The mill is completely lined with a protective liner on the inside. There are two types of liner: manganese steel and rubber. The drum has 5 rows, 180 pieces of liner in all, 36 in one row, and 22 pieces of liner lined in each of the input and output slots. The steel liner is made from Zavolzhye Engine Factory, while the rubber liner is imported from China. In the process of work, the liner of the drum and the mill wears down, limiting the resources of the mill.

The service life of the mill is approximately 15 years, and "Erdenet Industry" SOE increases this period with the help of repairs and technical services. At this time, the following 10 main tasks are performed:

1. Dismantling of the mill drum and part liner
2. Dismantling of the old mill
3. Remove the frame of the base plate of the thrust bearing.
4. Install the new mill drum
5. The assembly of the spindle bearing, drum, loading and unloading side and shell liner assembly under the supervision of the chief engineer of the manufacturer
6. Install all bolts of the drum, loading and unloading walls, shell liner according to the instructions of the chief engineer. Attached is a bolt tightening method.

7. Use the old transmission gear knob or install a new one. Do centralization of the drive shaft and half-shaft of the electric motor. Concrete-mortar casting of base slabs.
8. According to the instructions developed by the damage control department and the chief engineer, weld the drum body.
9. Conducting the focus of the transmission shell and measuring the distance.
10. set the drum, loading/unloading sections.

3.3 Modern methods of restoration of worn parts

Restoration of heavy machinery parts is an economically significant method for our country. In this field, many foreign and domestic researchers and scientists have developed and implemented restoration technology methods by conducting experimental research. It is a complex issue to develop and introduce remanufacturing technology because the service life of remanufactured parts is not less than that of new parts, and remanufacturing must be economically efficient.

The following methods are widely used for the restoration of the worn surfaces of parts that come into mechanical contact.

1. Polishing to the extent of repair
2. Chemical metallization
3. Cover with wear-resistant material
4. Electrolytic coating
5. Polymer coating

Polishing according to repair: This method was widely used in Russia and in our country it was widely used in engine repair. Remedial polishing is the removal of the worn part of the part by the polishing process.

In this way, it will be smaller than the original size, and a new bushing made of that size is used. The method of polishing and restoration is widely used in the repair industry because it reduces the duration of technological operations, reduces labor consumption and own costs, and eliminates the harmful effects of welding methods.

Metallization: This method is widely used in Russia, the United States, and some European countries. This is because the scientists and researchers of these countries have carried out extensive research on the direction of chemical installation of metals on the worn parts and surfaces of rapidly wearing parts, and have entered into use after calculating the results. The method of metallization involves coating the surface of the component with a metal precipitate in the form of ions in an aqueous solution [25].

Plastering with wear-resistant materials: This method is the most commonly used restoration method. It has been mentioned in the works of many researchers and scientists that the service life of repaired parts is greatly extended by this [6]. Wear-resistant surfaces of machine parts are coated with wear-resistant materials of various properties to increase their service life. The method of melting the coating using gas flame energy is widely used. Recently, electric arc welding and plasma and laser methods have become popular.

Electrolytic plating: This method belongs to the electrochemical method. Place the metal plates and articles in the metal salt solution and cover them. Direct current is supplied to metal plates and articles. This plate becomes the anode and the article becomes the cathode. As a result of the electrolysis, the platelets are eaten by the solution and carried by the electric current and sit on the surface of the product to form a coating. For example: It consists of metals such as copper, nickel, zinc, chromium, and lead [6].

Coating with polymer material: The surface of metal parts is coated with polymer material to protect it from the effects of the external environment. Polymer materials are multi-molecular organic compounds, both natural and artificial. The main raw materials for polymer materials are natural gas, oil, coal, wood, peat, and shale, which are composed of carbon and hydrogen.

By using these technological methods, the surface hardness and wear resistance of the restored parts can be improved. It is widely used in the repair industry because it eliminates the harmful effects of welding and brazing methods, which have a low thermal effect on the parts being repaired. The welding-welding method allows for effective restoration of metal parts and ensures a high level of product reliability and durability. So, the most commonly used welding processes in recent times are:

1. Shield Metal Arc Welding -SMAW
2. Gas Metal Arc Welding- GMAW
3. Flux Cored Arc Welding- GCAW
4. Gas Tungsten Arc Welding-GTAW
5. Oxy-acetylene Welding
6. Submerged Arc Welding- SAW

More than 70% of the parts being repaired are restored by welding and brazing [7] . Then the welding method is rapidly developing and modernizing. For example, in addition to choosing and using advanced equipment, the following items must be calculated when performing welding-welding restoration.

It includes:

- working condition and type of wear and tear of the restoration body
- cables and materials for paving
- welding methods for screeding
- suitable welding process
- suitable welding equipment

Other state-of-the-art techniques used in tissue reconstruction involve large amounts of force and temperature. It changes the characteristics of the component, creates residual stress, and causes various defects such as distortion of the material structure. For example, when welding is used, defects such as open and hidden cracks and pores, non-homogeneous hardness and structure, and loss of acceptable deviations in shape and size occur due to thermal stress.

3.3.1 The current state of restoration of worn out parts at Erdenet Industry SOE

Erdenet Industry, the largest center of metal processing and machine production in Mongolia, in the Repair Mechanics Plant (RMP) of SOE, not only manufactures parts that work in the most friction and wear environment of equipment, but also restores them within the limits of our resources. For example, ICHH28H2 white cast iron GRAT-1400, and other pump working wheels, wheels, and discs are made, while internal armor of ore grinding mills, cone crusher liner, excavator buckets, and shell are cast from 110G13L steel.

In addition to these, the main mining equipment such as KMD, KSD, KKD crushers, all types of mountain self-propelled heavy machinery and about 120 mud pumps of 12 types are being maintained.

In 1978, when the Mechanical Workshop of RMP of SOE "Erdenet Industry" was commissioned, 2,340 tons of metal structures, 500 tons of non-standard equipment, 720 tons of parts were restored, 2,482 tons of parts were mechanically processed, and 400 tons of repeated semi-finished products. , had the capacity to produce 200 tons of rubber products.

The workshop restores the worn parts necessary for the repair of the technological equipment of SOE "Erdenet Industry", equips the equipment parts with rubber, manufactures new spare parts, non-standard metal construction equipment, and ensures continuous and reliable operation of the plant. Currently, RMP uses the following two technologies for the restoration of worn parts of equipment.

1. Plastering with manual electric arc welding
2. Plastering the surface of the rotating part under the flux

Table 12 Lists the parts that are being repaired at RMP, grouped by equipment – Wear parts

	Equipment Name	Model	Quantity	Wears Parts
1	Crusher	KKD-1200/70	2	Fixed and moving armatures, cylinder heads, bevel driven gears, adjusting rings, bevel bodies, support blocks
		KMD-3000T2DP	6	
		KSD-2200T20D	5	
2	Mill	MSHTS-5.5x6.5	9	Drive gear, support shaft, support roller, sliding bearing, cover
		MMS 90x30	2	
		MSHTS-5.6x6.5	2	
		MSHTS-3.5x4.2	8	
3	Pump	GRAT-1400	30	Bearing, Gasket, Gasket mounting, protection disk
		GRAT-350	10	
		GRAT-170	10	
		GRAT-1400/40	10	
		8-GRK	10	
		Varman 14/16	5	
4	Excavator	EXC-15	2	Shell, bucket, drive gear, chain,
		EXC-12	4	
		EXC-10	6	
		Liebherr-R994	1	
		Liebherr-R9950	1	
	Total		123	

It can be seen that RMP regularly repairs more than 100 types of parts of approximately 4 types of equipment. As these equipment work in high friction and abrasive environments, the working surfaces and power transmission parts are mainly subject to wear. In the restoration of worn parts, manual insect welding and automatic welding under flux methods are used.

Chapter 4: Results and Discussion

4.1 Result of 5.5x6.5 mill

Figure 21 illustrates that the duration between WPU's technical services extends from 5 to 101 days, with a mean of 53,2 days. This data is based on the 2014 to 2020 ball mill of Erdenet Mining. The duration of technical service at the fifth mill varies from 62 to 217 hours, with an average of 73.7 hours. On average, maintenance is performed every two months. Regarding the fifth mill, 2126 working days and 126 repair days were recorded. The inspection examines the conditions including

1. Drum degradation
2. Torc liner corrosion
3. Pinion examination
4. Shell liner
5. Input/Output apparatus
6. The lubrication system

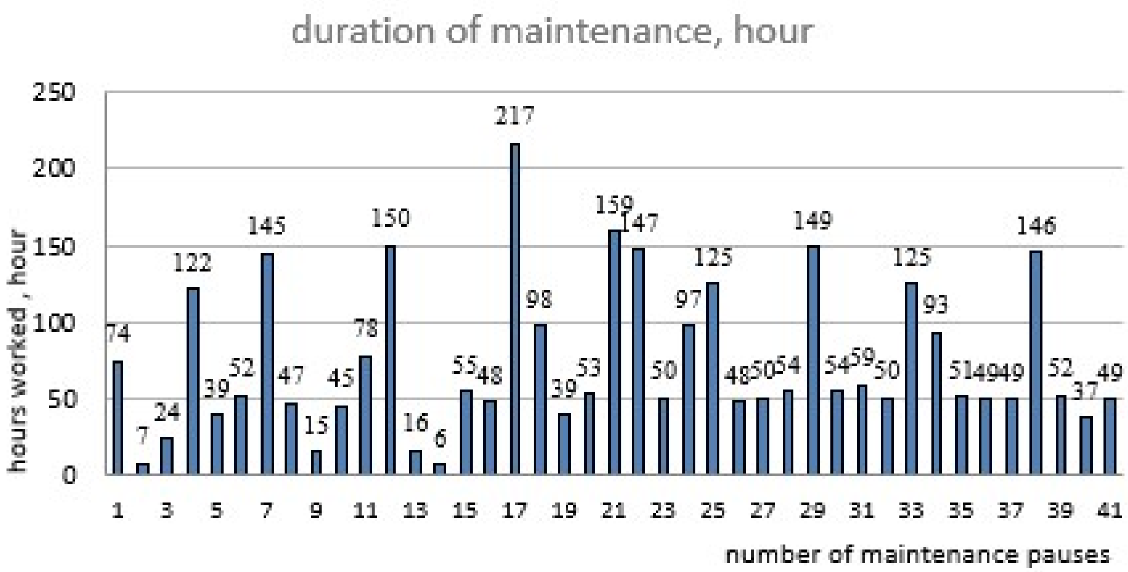


Figure 21 Maintenanace period in hour

From the repair history of the 5th mill, the parts that are mainly worn and replaced are selected, and their average service life is shown in Table .

Table 2 Time between revisions

	Time Between Revisions, day (TBR)							
	Output Liner		Input Liner		Drum Liner		Shell Liner	
	Working day	TBR	Working day	TBR	Working day	TBR	Working day	TBR
1	131	131	131	131	131	131	1730	1730
2	301	170	301	170	348	217		
3	348	47	348	47	566	218		
4	497	149	497	149	607	41		
5	544	47	544	47	835	228		
6	723	179	723	179	888	53		
7	947	224	947	224	1061	173		
8	1013	66	1104	157	1295	234		
9	1188	175	1403	299	1504	209		
10	1295	107	1644	241	1782	278		
11	1577	282	1809	165	2019	237		
12	1809	232	2019	210				
13	2019	210	2063	44				
Min		47		44		41		1730
Max		282		299		278		1730
Average		155.3076923		158.69231		183.5455		1730

4.1.1 State of MSHTC mill maintenance

The maintenance status of the mills used in the WPU was determined using aggregate log data. In doing so, the periodicity of maintenance of the 5th mill used in the WPU, the continuation of maintenance, and the periodicity of liner replacement of drums and grates were determined.

Figure 22 shows that periodicity for replacing mill liners and input/output liners. 26 replacements of output/input liners were performed over 2249 working days. After an average of 157 days of operation, input/output liners are replaced. In addition, 11 replacements of drum liner were performed as well as after an average of 184 days of operation.

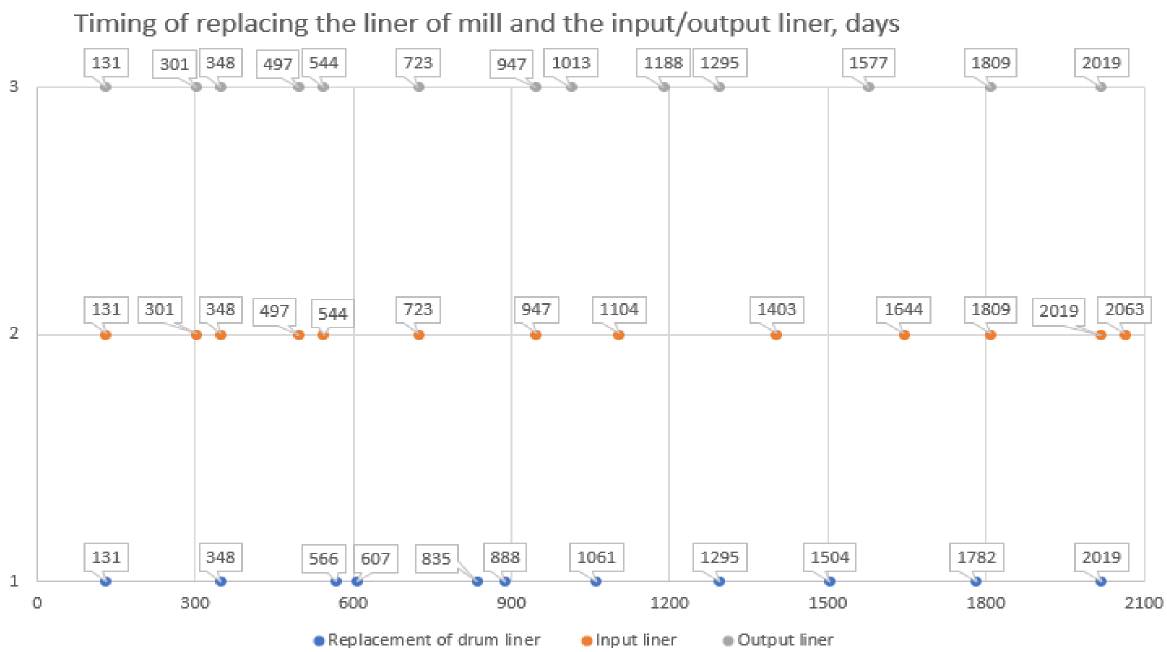


Figure 22 Replacing the liner of mill and input/output liners, days

Figure 23 shows that the shell liner of the fifth ball mill was replaced in October 2014 because it had been restored after 5 years and 1 month of operation.

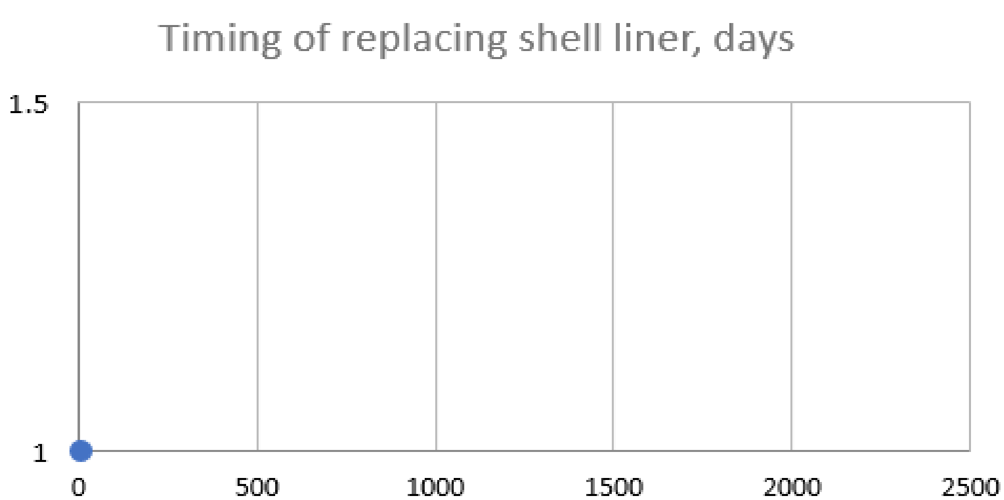


Figure 23 Timing of replacing shell liner, days

4.2 Analysis of spare parts consumption of MSHTS 5.5x6.5 mill

The number of replacements of metal and rubber liners, transmission gears, and shell liners for each mill served as the basis for evaluating the spare parts consumption of MSHTS mills. Currently, mills 2 and 5 are using rubber liner, and mill 1A.

Figure 24 The mill's interior with metal and rubber liner

BTU mills are divided into the following groups based on size and type of liner used.

1. Mills of MSHTS-5.5x6.5A group. Mills 3, 4, 6, 7 and 8 belong to this group
1. Mills 2 and 5 belong to MSHTS-5.5x6.5 group.
2. Mill 1
3. Mill 1A

Different types of mills use different liners and different sizes. Includes:

Use metal liner for mills 3, 4, 6, 7, and 8.

Name	Unit	Weight (kg)	Total
Torc	44	1233	54252
Drum (short)	36	320	11520
Drum (length)	144	450	64800
Total of drum	180	770	76320

Total	224	2003	130572

Use rubber liner for mills 2 and 5.

Rubber liner

Name	Unit	Weight (kg)	Total
Torc (plate)	32	160	5120
Torc (lifter)	32	110	3520
Drum (short)	54	400	21600
Drum (medium)	36	510	18360
Drum (length)	90	600	54000
Total of drum	180	1510	93960
Total	244	1780	102600

In the 1st mill

Name	Unit	Weight (kg)	Total
Torc	64	610	39040
Drum (short)	37	400	14800
Drum (medium)	70	510	35700
Drum (length)	73	600	43800
Total of drum	180	1510	94300
Total	244	2120	133340

in the 1A mill

Name	Unit	Weight (kg)	Total
Torc	32	1750	56000
Drum (short)	36	440	15840
Drum (medium)	72	510	36720

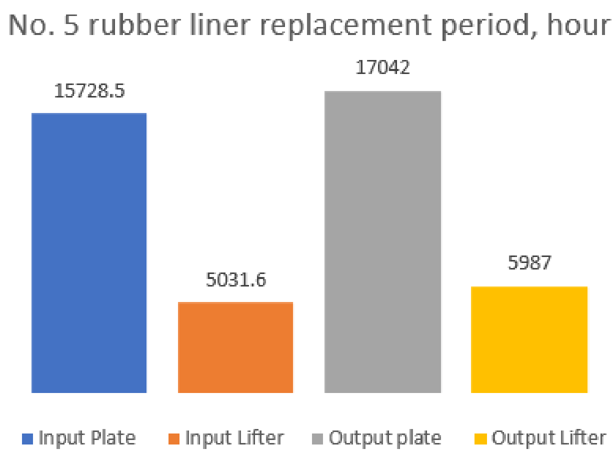
Drum (length)	72	600	43200
Total of drum	180	1550	95760
Total	212	3300	151760

As can be seen from above, many different liners are used in mill drums and mills. For example: In Torc: in addition to metal liners weighing 1230, 1750, 610 kg, 160 kg of tiles and 110 kg of lifters are used. Drum: 320, 400, 410, 440, 450, 510, 600 kg metal liner is used.

During the measurement period of each mill, the number of liner changes, the total number of liner used, and the evaluation of liner consumption per day were calculated.

Also, the material consumption of liner per 1 ton of crushed ore of each mill is evaluated and shown Table 4. In this way, rubber liner is used much less than metal liner. It turns out that the lifter consumes 2 times more than the plate.

Table 2 Daily consumption of rubber and metal liner



Mill	Input plate	Input lifter	Output plate	Output plate
5th	0.031	0.077	0.023	0.062

4.2.1 The most commonly used mill repair components

1. Liner
    - Drum manganese from ZEF or rubber made in China
    - Torque manganese from ZEF or rubber made in China
2. Pinion
3. Shell liner
4. Bearing

These are the most frequently replaced repairs.

Mill liner

There are 3 types of drum liner in MSHTC mills: manganese liner from ZMZ, rubber liner from NKMZ plant of Ukraine, and rubber liner made in China. ZMZ manganese and Chinese rubber liner will be used in the drum. When using rubber liner, use tiles and lifters.

Pinion and shell liner

It is responsible for transmitting the engine's torque to the mill's body. A shaft-shester and a shell liner constitute the gear transmission. We are using a Ukrainian transmission. In recent years, some mills have been outfitted with beast transmissions manufactured in China. Turning the worn side of the shaft and vane to the non-worn side increases the service life.

There is no restoration action after use. When the crankshaft is replaced, its bearing No. 3652 is also replaced. The gearbox with the pinion is recoverable. If the primary structure can be restored, it will be possible to restore the shell liner.

Input/Output liner

A section for loading ore in a mill and discharging it after milling, equipped with wheels. The working surface or internal part of the device wears out. It is repaired by welding.

Drum

After 10-15 years of operation, the mill body becomes unusable and needs to be replaced. Cracks formed during use are repaired and replaced with new ones when they are no longer repairable. At this time, complete installation work is done. This includes foundation casting, positioning, measuring, filling, inspection and test firing.

Conclusion

The comprehensive study on the service life and maintenance practices of the mill at "Erdenet Industry" SOE provides valuable insights into the lifecycle of this critical machinery. The standard service life of the mill is approximately 15 years; however, through regular maintenance and technical services, the organization has successfully extended this lifespan. The mill maintenance involves a ten-step process, starting from dismantling the mill drum to setting the drum, loading/unloading sections.

In the maintenance process, welding techniques play a significant role, with more than 70% of the parts being restored through welding and brazing. With the advancement of technology, the welding methods used in the industry have modernized, offering more reliable and durable repair solutions. However, it is essential to carefully choose the right welding process, equipment, and materials for each restoration to ensure the structural integrity of the mill components. The study also highlighted some challenges, such as the possibility of residual stress and material distortions due to the high force and temperature involved in these processes.

Two technologies, namely, plastering with manual electric arc welding and plastering the surface of the rotating part under the flux, are employed in the restoration of worn parts of equipment at the workshop. This approach ensures the continuous and reliable operation of the plant.

Analysis of historical data from the 2014 to 2020 ball mill of Erdenet Mining shows that the mean duration between technical services is 53.2 days, with maintenance performed roughly every two months. This systematic approach to maintenance has been effective, with the 5th mill recording 2126 working days against 126 repair days.

The maintenance status of the mills is determined through a thorough examination of various critical conditions such as drum degradation, torc liner corrosion, pinion examination, shell liner, input/output apparatus, and the lubrication system.

In conclusion, the mill maintenance practices at "Erdenet Industry" SOE demonstrate a well-structured and systematic approach, leveraging modern technologies to extend the service life of the mill. While challenges remain, the commitment to regular inspections, maintenance, and the use of advanced welding techniques have ensured high levels of reliability and durability in the mill's operation.

Future work

Implementing the technology for control and optimization of a Ball mill circuit for iron ore processing would be the next step. This includes the further development of power-efficient sensors, telemetry systems (wireless sensors), data pre-treatment methods for signal processing, and data compression.

Several necessary enhancements have been identified in order to increase the accuracy of DEM prediction and permit quantitative comparisons with measured data. This includes laboratory research on lifter relaxation, simulation of time-dependent lifter behavior, and extension of the approach to a three-dimensional DEM mill model.

References

[1] C. A. Y. S. Komar Kawatra, SME mineral processing & extractive metallurgy handbook, Colorado : Society for Mining, Metallurgy & Exploration (SME), 2019.

[2] J. T. Karlheinz Spitz, Mining and the Environment, London: CRC Press, 2019.

[3] C. D. C. D. P. Lucia Mancini, ecurity of supply and scarcity of raw materials: Towards a methodological framework for sustainability assessment., 1 ed., Luxemburg: Publications Office for the European Union, 2013.

[4] M. Insider. [Online]. Available: https://markets.businessinsider.com/commodities/copper-price.

[5] S. Mukherjee, Applied Mineralogy, New Delhi: Springer, 2012.

[6] U. G. Survey, "MINERAL COMMODITY SUMMARIES 2020," Washington, 2020.

[7] M. Garside, 2023. [Online]. Available: https://www.statista.com/statistics/273637/copper-reserves-by-country/.

[8] J. I. C. A. (JICA), "DATA COLLECTION SURVEY ON COPPER INDUSTRY SECTOR IN MONGOLIA," Ulaanbaatar, 2014.

[9] S. K. Kawatra, "Advances in communication," *Kawatra S. K. (2006). Advances in comminution. Society for Mining Metallurgy and Exploration. Retrieved May 16 2023 from http://www.knovel.com/knovel2/Toc.jsp?BookID=3902.,* p. 557, 2006.

[10] P. W. Cleary, "Ball motion, axial segregation and power consumption in a full scale two chamber cement mill," *Minerals Engineering ,* vol. 22, no. 9-10, pp. 809-820, August-September 2009.

[11] H. Usman, "Measuring the efficiency of the Tumbling Mill as a Function of lifter configurations and operating parameters," Colorado, 2017.

[12] C. M. S. D. M. Q. Steven J. Spenser, "Stereotype Threat and Women's Math Performance," *Journal of Experimental Social Psychology,* vol. 35, no. 1, pp. 4-28, January 1999.

[13] F. Núñez, "Characterization and Modeling of Semi-Autogenous Mill Performance under Ore Size Distribution Disturbances," *IFAC Proceedings Volumes,* vol. 44, no. 1, pp. 9941-9946, August 2011.

[14] T. J. M. S. M. R. D. K. T. Napier-Munn, Mineral comminution circuits: their operation and optimisation, vol. 2, T. J. Napier-Munn, Ed., Julius Kruttschnitt Mineral Research Centre, University of Queensland, 1996.

[15] J. A. F. F. F. P. Barry A. Wills, Wills' Mineral Processing Technology, 8th ed., Amsterdam: Elsevier, 2015.

[16] R. M. S. M. Paul W Cleary, "Comparison of DEM and experiment for a scale model SAG mill," *International Journal of Mineral Processing,* vol. 68, no. 1-4, pp. 129-165, January 2003.

[17] T. L. Z. Z. S. Z. a. Z. Y. Yuxing Peng, "Discrete element method simulations of load behavior with mono-sized iron ore particles in a ball mill," *Advances in Mechanical Engineering,* vol. 9, no. 5, pp. 1-10, 2017.

[18] C. Arekar, "Real time analysis with development, simulation and validation of discrete element method models for tumbling mill charge motion and liner wear," Canada, 2004.

[19] J. T. Kalala, "Discrete element method modelling of forces and wear on mill lifters in dry ball milling," Johannesburg, 2008.

[20] I. Finnie, "Some observations on the erosion of ductile metals," *Wear,* vol. 19, no. 1, pp. 81-90, January 1972.

[21] K. Tano, "Continuous Monitoring of Mineral Processes," 2005.

[22] R. R. P. S. B. M. S. Agrawala, "Mechanics of media motion in tumbling mills with 3D Discrete Element Method," *Minerals Engineering,* vol. 10, no. 2, pp. 215-227, February 1997.

[23] J. Watson, "An analysis of mill grinding noise," *Powder Technology,* vol. 41, no. 1, pp. 83-89, January 1985.

[24] E. M. Corporation, 2022. [Online]. Available: https://en.wikipedia.org/wiki/Erdenet_Mining_Corporation. [Accessed 20 January 2023].

[25] U. G. Survey, "Mineral Commodity Summaries 2020," 2020.

[26] I. A. F. A. M. K. G. Alafara Abdullahi Babam, "A Review on Novel Techniques for Chalcopyrite Ore Processing," *Mining Engineering and Mineral Processing,* vol. 1, no. 1, pp. 1-16, May 2012.

[27] G. I. Mongolia, 2021. [Online]. Available: https://gratanet.com/laravelfilemanager/files/3/Mining%20Mongolia_2021%20ENG.pdf.

[28] S. K. Kawatra, Advances in comminution, Colorado: Society for Mining, Metallurgy, and Exploration, 2006.

[29] M. S. S. I. R. P. C. P. R. B. E. K. &. S. L. Powell, "The selection and design of mill liners," *In Advances in Comminution,* pp. 331-376, 2006.

[30] P. Cundall, "A computer model for simulating progressive, large-scale movements in blocky rock systems," *Proceedings of the Symposium of the International Society for Rock Mechanics,* vol. II, no. 8, 1971.

[31] H. Moys, "Model of Mill Power as Affected by Mill Speed, Load Volume and Liner Design," *Journal of South Africa Institution of Mining and Metallurgy,* vol. 93, no. 6, pp. 131-141, June 1993.

[32] R. K. R. B.K. Mishra, "Simulation of charge motion in ball mills. Part 1: experimental verifications," *International Journal of Mineral Processing,* vol. 40, no. 3-4, pp. 171-186, February 1994.

[33] g. Evan, "A new method for determining charge mass in AG/SAG mills.," *Proceeding SAG ,* vol. 2, pp. 331-345, 2001.

[34] Y. G. a. M. M. Jaspan R.K., "ROM mill power draft control using multiple microphones to determine mill load," *Proc. of International conference on Gold,* vol. 2, pp. 483-392, 1986.

[35] J. Kolacz, "Measurement system of the mill charge in grinding ball mill circuits," *Minerals Engineering,* vol. 10, no. 12, pp. 1329-1338, December 1997.

[36] S. A. N. T. T.A. Apelt, "Inferential measurement of SAG mill parameters," *Minerals Engineering,* vol. 14, no. 6, pp. 575-591, June 2001.

[37] J. Kolacz, "Measurement system of the mill charge in grinding ball mill circuits," *Minerals Engineering,* vol. 10, no. 12, pp. 1329-1338, December 1997.

[38] E. M. Corporation. [Online]. Available: https://en.wikipedia.org/wiki/Erdenet_Mining_Corporation. [Accessed 20 January 2023].

[39] T. N.-M. Barry A. Wills, Wills' Mineral Processing Technology, 7th ed., Oxford : Oxford: Butterworth-Heinemann, 2006.

[40] S. Morrell, "The Prediction of Power Draw in Wet Tumbling Mills," 1993.

Appendix

1	20/10/2014	23/10/2014	74	5	5

2	28/10/2014	28/10/2014	7	5	10
3	14/12/2014	15/12/2014	24	31	41
4	15/1/2015	20/1/2015	122	48	89
5	9/3/2015	10/3/2015	39	69	158
6	18/5/2015	20/5/2015	52	101	259
7	29/8/2015	4/9/2015	145	47	306
8	21/10/2015	23/10/2015	47	60	366
9	22/12/2015	22/12/2015	15	34	400
10	25/1/2016	27/1/2016	45	55	455
11	22/3/2016	25/3/2016	78	47	502

12	11/5/2016	17/5/2016	150	22	524
13	8/6/2016	9/6/2016	16	41	565
14	20/7/2016	22/7/2016	6	59	624
15	19/9/2016	21/9/2016	55	57	681
16	17/11/2016	19/11/2016	48	61	742
17	19/1/2017	28/1/2017	217	51	793
18	20/3/2017	24/3/2017	98	53	846
19	16/5/2017	17/5/2017	39	59	905
20	15/7/2017	17/7/2017	53	66	971
21	21/9/2017	27/9/2017	159	48	1019
22	14/11/2017	20/11/2017	147	43	1062
23	2/1/2018	4/1/2018	50	84	1146
24	29/3/2018	2/4/2018	97	38	1184

25	10/5/2018	15/5/2018	125	69	1253
26	23/7/2018	25/7/2018	48	56	1309
27	19/9/2018	21/9/2018	50	52	1361
28	12/11/2018	14/11/2018	54	51	1412
29	4/1/2019	10/1/2019	149	50	1462
30	1/3/2019	3/3/2019	54	73	1535
31	15/5/2019	18/5/2019	59	67	1602
32	24/7/2019	26/7/2019	50	70	1672
33	4/10/2019	9/10/2019	125	68	1740
34	16/12/2019	20/12/2019	93	27	1767
35	16/1/2020	18/1/2020	51	71	1838
36	29/3/2020	31/3/2020	49	41	1879
37	11/5/2020	13/5/2020	49	49	1928

38	1/7/2020	7/7/2020	146	49	1977
39	25/8/2020	27/8/2020	52	44	2021
40	10/10/2020	12/10/2020	37	63	2084
41	14/12/2020	16/12/2020	49		

1	16484	7276	16484	7276	10.5	7.5
2	17498	4698	17337	4698	8.5	8.5
3	14804	3913	17304	3913	10	8
4	14128	5774		7173	6	8
5		4203		7139	7.5	7.5
6		4565		6573	8	8
7		3900		6652	8	8
8		5428		4471	9.5	9.5
9		4883				
10		5676				
max	17498	7276	17337	7276	10.5	9.5
min	14128	3900	16484	3913	6	7.5

average	15728.5	5031.6	17042	5987	8.5	8.125

1	15/1/2015	20/1/2015	6656	2249	6656	2249
2	9/3/2015	10/3/2015	7802	3395	7802	3395
3	18/5/2015	20/5/2015	9442	4928	9442	4928
4	29/8/2015	4/9/2015	11786	7276	11786	7276
5	21/10/2015	23/10/2015	12925	1139	12925	1139
6	22/12/2015	22/12/2015	14366	2580	14366	2580
7	25/1/2016	27/1/2016	15166	3380	15166	3380
8	22/3/2016	25/3/2016	16484	4698	16484	4698
9	11/5/2016	17/5/2016	1032	1032	1032	1032
10	8/6/2016	9/6/2016	2549	2549	2549	2549
11	20/7/2016	22/7/2016	3913	3913	3913	3913
12	19/9/2016	21/9/2016	9379	1815	9379	1815
13	17/11/2016	19/11/2016	10848	3284	10848	3284
14	19/1/2017	28/1/2017	12069	4504	12069	4504
15	20/3/2017	24/3/2017	13339	5774	13339	5774
16	16/5/2017	17/5/2017	14738	1443	14738	7173

17	15/7/2017	17/7/2017	16236	2941	16236	1923
18	21/9/2017	27/9/2017	17498	4203		
19	14/11/2017	20/11/2017				
20	2/1/2018	4/1/2018	12791	2552	14414	4216
21	29/3/2018	2/4/2018	14804	4565	16427	6229
22	10/5/2018	15/5/2018	910	910	17337	7139
23	23/7/2018	25/7/2018	2529	2529	1631	1631
24	19/9/2018	21/9/2018	3900	3900	3002	3002
25	12/11/2018	14/11/2018	5098	1265	4200	4200
26	4/1/2019	10/1/2019	6313	2480	5415	5415
27	1/3/2019	3/3/2019	7471	3638	6573	6573
28	15/5/2019	18/5/2019	9261	5428	8363	1785
29	24/7/2019	26/7/2019	10264	1595	9942	3364
30	4/10/2019	9/10/2019	12500	3255	11602	5024
31	16/12/2019	20/12/2019	14128	4883	13230	6652
32	16/1/2020	18/1/2020	647	647	13480	647
33	29/3/2020	31/3/2020	2344	2344	15177	2344
34	11/5/2020	13/5/2020	3327	3327	16160	3327

35	1/7/2020	7/7/2020	4471	4471	17304	4471
36	25/8/2020	27/8/2020	5676	5676	1205	1205
37	10/10/2020	12/10/2020	6658	1031	2187	2187
38	14/12/2020	16/12/2020	8189	2562	3718	3718