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ADDIS ABABA INSTITUTE OF TECHNOLOGY

CENTER FOR ETHIO-MINES DEVELOPMENT

Title: Grindability and Comminution Energy Consumption in Case of Midroc (Lega Dembi and Sakaro) Gold Ore

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This project was submitted to fulfill some of the Master's degree requirements. By Mineral engineering in the field of engineering.

Sept 21th, 2023

Declaration

Author: Yonas Hordofa Ferada sign -------------------------

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Approved by: -------------------------------sign-------------------------

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I authorize that the work described above is entirely my own.

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Abstract

The purpose of this study was to investigate the impact of mill speed and grinding time on the grindability and comminution of gold ores from the Lega Dembi and Sakaro deposits. A batch mill internal diameter of 200 mm and volume (5 dm3) was used for the experiment. The study employed a two-factor approach, considering different grinding times (10 and 15 minutes) and three fractions of mill critical speed (40%, 50%, and 60%).The experiment involved dividing the feed into five equal portions across eleven size class fractions ranging from 4mm to -75µm, with a √2-series interval. A total of ten kilograms of material, divided into one-kilogram portions, were used for the experiment. The objective of maintaining a critical speed below or equal to 50% was to minimize energy consumption during the milling process. The study aimed to assess both the grindability and energy consumption of the two deposits. The results of the study indicated that the rate of breakage increased with grinding time rather than mill speed. For the Lega Dembi deposit, at 40%, 50%, 60% speed and 15 minutes grinding time, the amounts of desired particle size classes produced were 251.7 grams, 264 grams, and 263 grams for the different mill speeds. Similarly, for the Sakaro deposit, the amounts produced were 251.7 grams, 232.6 grams, and 256 grams for the respective mill speeds. Based on the obtained results, the study concluded that mill speed had no significant effect on the grindability of the gold ores from both mining sites, as grinding times.

Key terms: Mill speed, grinding time, grindability, comminution, energy consumption, mill critical speed, gold ore.

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S/No	Symbols	Names
1	HPGR	High pressure grinding role
2	CCP	Complete characterizing package
3	GCT	Geo metallurgical test
4	RPM	Revolution per minute
5	ϕc	Rotational speed of mill

6	J	The volume of mill occupied by ball
7	U	The volume of mill occupied by ore/rock
8	R	Residence time of ore in mill
9	L	Level
10	K	factors
11	µm	Micron
12	W	J/h
13	Kwh/t	Wi / Work Index
14	cf	Correction factor
15	W/P	Work/ power
16	E	Energy
17	LPG	Liquefied petroleum gas
18	UFG	Unaccounted For Gas
19	‘	Minute
20	%	Percent

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1. INTRODUCTION

Researchers have worked hard to advance mineral processing over the years despite it being known for many decades. Although comminution is one of the most crucial steps in the mineral processing chain, it also requires the greatest energy (Wills & Finch, 2016).

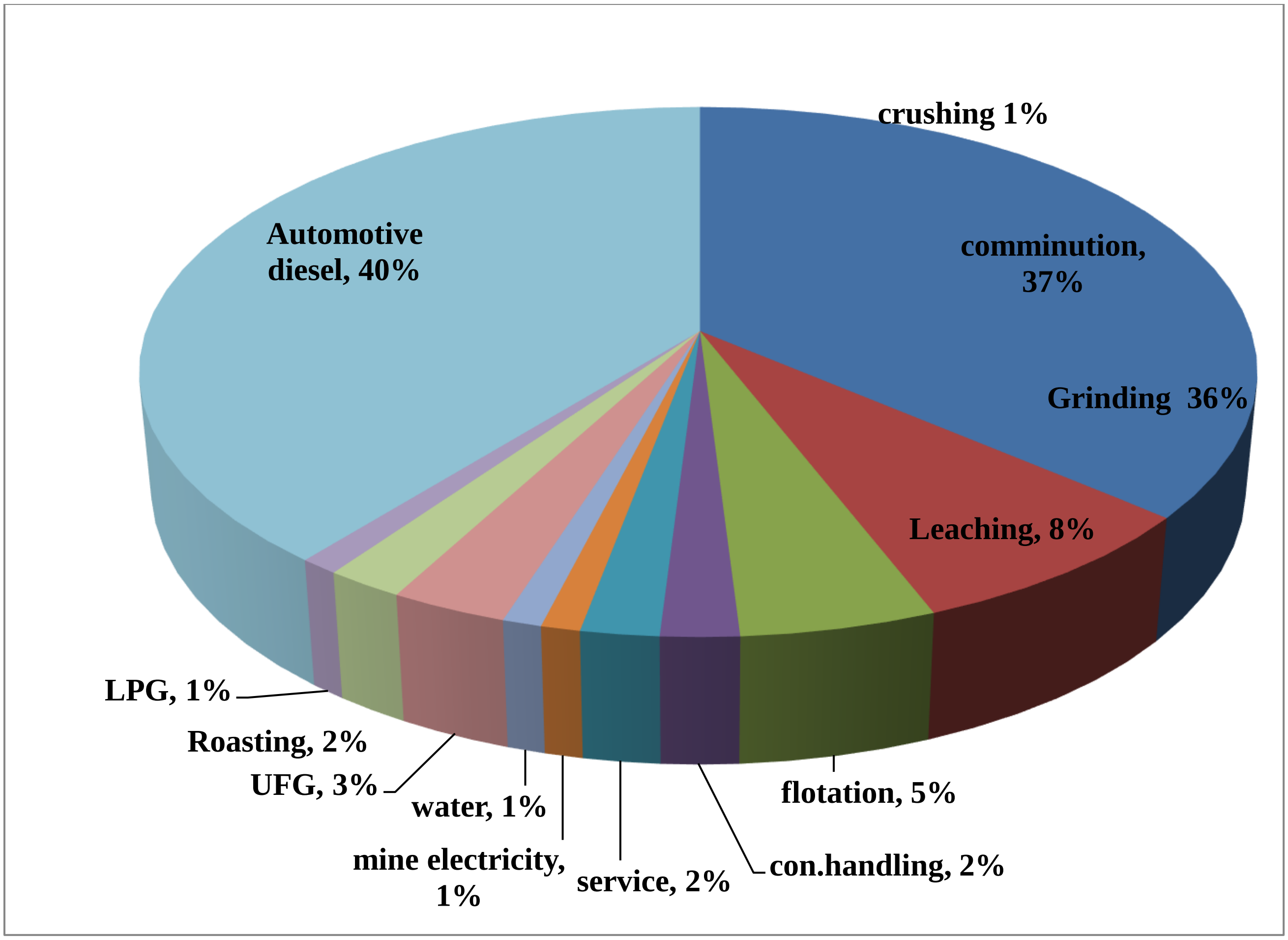


Figure 1: An example of an energy audit, expressed in terms of CO_2 emissions, conducted on Kalgoorlie Consolidated Gold Mine in 2005 (Ballantine & Powell, 2014)

The goal of comminution is to either reduce the size to that of the finished product or to free the valuable minerals from the gangues or unintended minerals for separation up front in the downstream processing processes. For efficient concentration and improving the quality of the final concentrate of complex mineral particles, particle size and particle grades are often factors of interest.

When grinding is the focus of research, the most pertinent variables are those that can be measured experimentally to quantify the desired particle size class, such as grind ability, Work indices, and reduction ratios, as well as modeling techniques like population balance models. The quantity of energy needed varies depending on the mineralogy, texture, design of the grinding circuit, and grinding circumstances such as mill rotation speed and ore residence time. However, a significant portion of the energy supplied is wasted on energy-expensive processes outside of the energy's immediate clash with the ore (Somani et al., 2017). The degree of mineral liberation is a crucial definition in the design of the comminution process. Lower-quality concentrate is the result of many valuable minerals not being fully liberated from gangues, or untargeted minerals .additionally valuable minerals being lost in with tailings or gangues minerals. Hence, achieving these goals requires high-energy consumption in the comminution unit process. Varied ore with varied grain sizes responds differently to texture in terms of its capacity to be ground. Fine grain ore has a higher breakage rate and grindability than medium and coarse grain ore, and it creates more fines up until the point at which the ore is completely released, at which point no fine grains are produced and only energy is lost. This indicates that there is no size change when the mineral is entirely freed but an increase in energy consumption (Ghanei, 2019).

Many researchers have been involved in the use of HPGR (High Pressure Grinding Roll) in conjunction with Ball mills to reduce energy usage according to Hamid et al. (2018). Mineral release increases as particle, size is reduced. Other researchers have also discovered that utilizing various crushing and grinding design will considerably boost mineral liberation at even coarser particle size distributions (Apling & Bwalya, 1997). However, some researchers contend that liberation performance and efficiency are independent of the machine and instead depend on the ore texture, with the same ore body capable of exhibiting a range of liberation performance and efficiency (Ghanai, 2019). According to Somani et al. (2017), new technology has recently been developed to improve the liberation of target minerals by pretreating ore using one or more of the following methods: thermal breakage, microwave heating, high-voltage pulse breakage, ultrasonic breakage, thermal shock, and thermal breakage.

Overall, a number of variables, such as the kind of grinding, the design of the circuit, and the properties of the materials, affect mineral liberation. The goal of this research was to investigate the energy consumption of the mineral processing industry. The issue of interest was grinding conditions, such as the impact of mill rotation speed and ore residence lengths in mills.

1.1. Statement of problems

Comminution is a crucial process in mineral processing that involves reducing the size of particles. It is responsible for a significant portion (30-70%) of the total energy consumption in mining operations. However, advancements in technology, such as (HPGR), have shown potential in reducing energy usage by 20-50% (Wills & Finch, 2016).

The design of the comminution unit plays a vital role in its efficiency. Poorly designed units can lead to increased wear on media and liners. Moreover, a substantial amount (over 90%) of the energy consumed during comminution is lost as heat, movement, and particles that do not break apart as desired (Somani et al., 2017). This highlights the need for optimizing the comminution process to minimize energy waste.

The size of particles decreases as the mill rotation speed increases, but beyond a certain point, further increases in rotation speed do not significantly reduce the particle size. This excessive rotation only results in energy wastage. Many plants operate within the "critical speed" range without considering the energy inefficiency. Studies have shown that 65-90% of the critical speed is commonly used but may not be the most efficient range (Makgoale (2019). Speeds above 90% do not grind particles effectively, while low speeds can cause particle breakage through friction and pressure. Therefore, it is essential to investigate the relationship between breakage and energy consumption at low mill rotations.

To address these concerns, testing at low mill rotations with short residence times is conducted to maximize the desired particle size classes while minimizing energy consumption. The objective is to identify the optimal conditions for comminution, taking into account the specific characteristics of both the Lega Dembi and Sakaro deposits within the Midroc Gold Mine PLC. Understanding the links between breakage and energy usage under specific conditions is crucial in improving the efficiency of the comminution

1.2. **Objective**

1.2.1. General objective

The main objective of this study increases ball mill performance and maximizes mill efficiency based on the relationship between rotation speed, and residence time of ore in the mill in the case of specific ore of Lega Dembi and Sakaro Deposit gold ore.

1.2.2. Specific objectives

- Maximize desired size class
- To estimate energy required to liberate the target mineral
- Estimate the performance of the batch ball.

1.3.Research questions

- How does the low rotational speed of a ball mill and residence time affect the breakage rate of specific ore?
- How does maximizing the desired size class at low energy consumption?

1.4.Significance of the study

- This study gives information for any company's related to excessive energy consumption on comminution; how to maximize desired size by optimizing rotational speed and residence time of ore in mill.
- The research project will provide researchers with experimental values, which will be useful for pilot scale testing, as well as contribute to the academic discourse and debate within this discipline.

2. Literature Review /Comminution Theory

Many minerals start in a locked state, needing comminution to first unlock or liberate them. Comminution is used as the size reduction process to liberate the target minerals after it begins, since most minerals are initially finely mixed with gangue material. This allows comminution to achieve a desired particle size or separation from undesirable minerals. Comminution represents the primary stage of size reduction, where grinding then comprises the secondary stage (Wills & Finch, 2016).

2.1. Breakage patterns in comminution

A variety of fracture processes may occur when an ore is strained depending on the characteristics of the material as well as the type, quantity, and rate of stress. The three main categories of breaking processes, according to Ghanai (2019), are shattering, cleavage, and attrition. However, none of the large ideal breaks happens on their own.

2.1.1. Shattering/fracture

This fracture mechanism happens when rapid compressive stress or impact is applied.

Figure 2: Fracture mechanism of the particles; shatter (Ghanei, 2019)

The product will come in a variety of sizes due to the unselective nature of this method (Figure 2). That progeny particle will be subject to more Breakage because of the occurrence of several fracture processes. There are several processes involved in the shattering process, not simply one fracture step. These processes involve first breaking up the parent particle, which will then be followed by breaking up consecutive generations of daughter fragments, and so on, until all of the energy that can be used to break something is used up. These subsequent fractures happen in a relatively short period and, on a larger time scale, they appear to be one event. In industrial ball, rod, and autogenously mills, shattering is the most frequent type of fracture (Ghanei, 2019).

2.1.2. Cleavage

When the original solid has multiple preferred planes along which fracture is likely to occur, cleavage breaking occurs. In the case of a single particle fracture, this process of fracture will result in a number of relatively big fragments that correspond to the parent particle's grain size, with considerably finer particles coming from the stress application points (Figure 2). The product's particle size distribution is uniform. However, will frequently be bimodal or even multi-modal. (Ghanei, 2019)

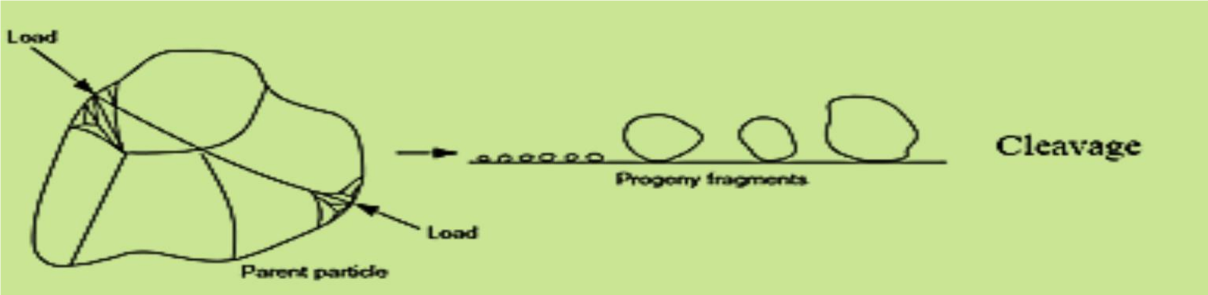


Figure 3: *Fracture mechanisms of the particles, cleavage* (Ghanei, 2019).

Kelly and Spotswood (1990) to describe cleavage utilized the energy rate imparted to a particle. In the scenario described where energy is slowly applied to a single, relatively large particle, primary fracture may occur when the weakest flaw in the particle is overloaded. This means that the energy applied causes the particle to break apart at the point where the flaw is located. The easiest way to define such a fracture is as a cleavage (Kelly and Spotswood, 1990).

2.1.3. Attrition

The energy rate that is applied to a particle is how Kelly and Spotswood (1990) described cleavage. When energy is slowly applied to a single, relatively large particle, primary fracture may happen just as the weakest flaw becomes overloaded. This fracture will result in the unloading of the product particles, and the size distribution will include a few particles that are relatively similar in size to the original one. According to Kelly and Spotswood (1990), the best way to define such a fracture is as a cleavage.

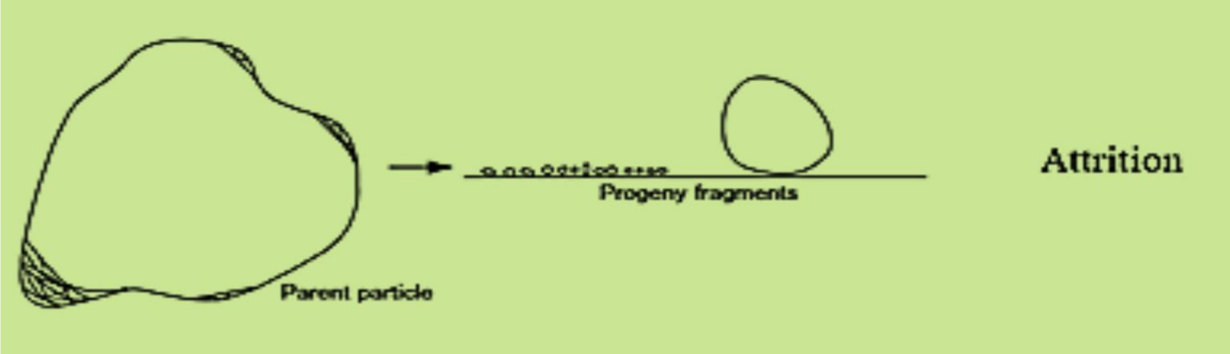


Figure 4: *Fracture mechanisms of the particles, attrition* (Ghanei, 2019)

2.2. Particle size distribution after breakage

The particle size and density distribution for the offspring particles after attrition exhibits a clear peak at the Small sizes. However, which is clearly distinct from the peak produced by the lingering parent particles. A size range with almost no particles separates the two Peaks. In the event of cleavage, there are also two peaks, one at medium-size particles and one at nearly parent-size particles, which are close to one another. There is no distinct peak in the particle sizes in the case of fracturing. The probability of occurrence is the same for all particle sizes, as illustrated in the picture below.

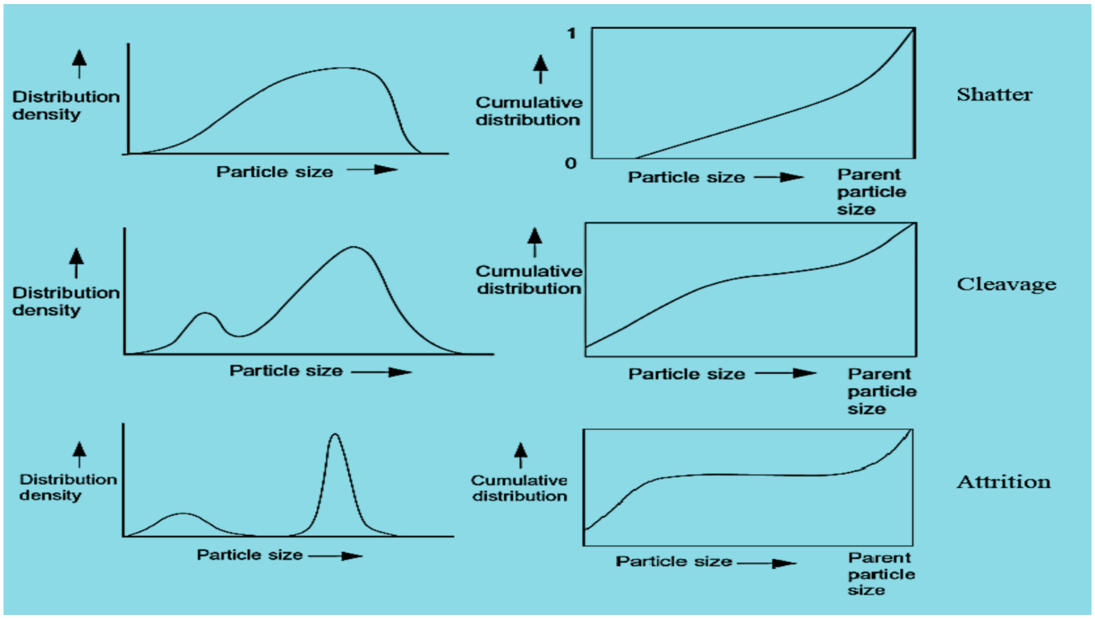


Figure 5: The particle size distributions for the different breakage mechanisms (Ghanei, 2019)

Table 1: Factors that affect grind ability and comminution energy consumption

No	Factors that affect grindability and combination energy consumption		Result	Reference
1	Rotational speed	Interest factors in this paper	revolutions per minute (rpm), of the ball in the mill to calculate the critical speed beyond which operation diverts	Mulenga & Moys, (2014) Deniz (2013) Makgoale (2019)
2	Residence time		Long residence time is needed to produce fine products but energy consumption so increase	Makgoale (2019)
3	Mill size		Large size of mill has high performance but less efficiency	Cho et al., 2013
4	Ball size		Large balls for coarse ores and vice versa, size difference balls preferable to similar size balls, to increase efficiency, and save energy consumption	Cho et al., 2013
5	Ball filling		Optimum ball number needed to perform mill efficiency, if not ball-ball, and ball-liner contact increase and energy consumption increase	Zhao et al., 2016
6	Ore filling/powder		Neither under filled nor overfilled. if under filled ball-ball or ball–liner contact increases energy consumption high, if overfilled powder cushioning formed decreases the breakage performance of the mill	Deniz and Onur (2002)

7	Texture	coarser grain size minerals can be separated from finer grain size, minerals can be liberated with less energy Consumption.	(Ghanei, 2019)
8	Feed rate	Uniform preferable than random	
9	Feed size distribution	Bigger particles break more easily than small particles, bigger size has larger flaws, easy break with little energy than fine size particle.	Tavares and king, 1998
10	Mineral association and association index matrix	Across or along grain boundary breakage may occur theoretically, if the associated mineral is more locked with the target mineral, the liberation of the target mineral need fine grinding indirect high energy consumption required	(Parian et al., 2018)
11	Slurry density	Dense slurry decrease size reduction efficiency, also if the slurry is diluted metal-metal contact increases energy consumption	(Tangsathitkulchai, 2003); Makgoale (2019)

However, among these, this paper is interested in the rotational speed of the mill, and the residence time of ore in the mill making other factors constant.

2.3. Effect of a rotation speed of mill and residence time of ore in the mill on Mineral processing energy consumption

2.3.1. .Rotational speed

In the mining sector, it is standard procedure to rate a mill is rotating speed as a percentage of its critical speed. A single ball fed into the mill reaches its critical speed when it begins to adhere to the mill wall theoretically. It was computed as follows in (rpm) (Makgoale (2019)

Critical speed (Nc) = $\frac{42.3}{\sqrt{D-d}}$……………………………………………………………………1

Where D is the mill's diameter in meters (m) and d is the largest ball's loaded diameter in meters. The rate of wear suffered by the grinding balls and shell liners, as well as the nature of the product, is all determined by the speed at which a mill operates. The mill speed affects the tumbling movement as well (Gupta & Yan, 2006). Demonstrated that in order to reduce energy consumption, mills should be operated at speeds between 50 and 90 percent of their critical speed. However, in an effort to reduce energy consumption, Makgoale (2019) found the desired size class at a slower rotating speed. The motion of the charge can be classified as cascading, cataracting, or centrifuging, depending on how quickly the mill rotates. When the mill rotates at a low speed, that is, 50% or below of the critical speed, the cascade motion happens. Additionally, there is greater production of high-quality products and a more prevalent attrition and compression breakdown mechanism. When a mill's speed rises above 50% of its critical speed, an impact brakeage mechanism commonly occurs, high energy dissipates, and coarse product is produced. The cataracting charge motion is created. Due to these factors, this project focused on low speed and quick turnaround efforts. Because of the global challenge of energy consumption, this paper needs to be optimized from both an energy cost and environmental perspective.

2.4. Investigation of material response to grinding and comminution energy consumption

2.4.1. Grind ability test

The grindability of gold ore can range from 3 to 42 kWh/t, depending on the association of gangues and the location of gold (Michaud, 2022). Grindability refers to the ease with which a material can be ground, and it is typically expressed in terms of energy consumption per unit mass of material.

The amount of material generated in a grinding stage that is smaller than a specified size can be determined by considering the net specific energy utilized in that grinding stage, which is the energy required for grinding multiplied by the mechanical efficiency of the grinding device. This value is then divided by the output of the grinding stage in terms of material.

To calculate grindability, it is necessary to specify the desired size class. The control sieve, which determines the size class, is chosen based on the prevailing target mineral texture. Different target minerals may have different optimal size ranges for effective liberation and recovery.

For conducting grinding test experiments using readily available mills, the author of the paper suggests using the GCT mill (geometallurgical comminution test mill) or a ball mill. The choice between these mills depends on the specific requirements and objectives of the experiment. The GCT mill is a specialized mill designed for geometallurgical testing and can provide valuable insights into the comminution behavior of the ore. Depending on the results obtained from the GCT mill, the scaling factor of 4 can be applied to estimate the performance of a larger-scale ball mill.

It is important to select the appropriate grinding device and methodology based on the specific goals of the study, the available resources, and the characteristics of the ore being tested. Proper selection and careful experimentation can provide valuable information about the grindability and comminution behavior of gold ore, which is crucial for efficient processing and optimization of mineral recovery.

Using Equation **2:** The grinding ability for different ores is the calculated as:

Grindability) =Product finer than a specific size, kg - Feed finer than a specific size (kg)/ --------2

Net specific energy

2.4.2. Bond work index

The Bond work index is a measure of the energy required to reduce a given material from a specific feed size to a particular product size. It is commonly used in the mining and mineral processing industry to assess the grindability of ores and determine the energy requirements for grinding operations.

The Bond method, developed by Bond (1961), is widely used for measuring the Bond work index. However, it does have some drawbacks. One of the drawbacks is that it requires a lengthy processing time, which can be time-consuming. Additionally, it requires a substantial sample mass, typically around 10 kilograms, which may not always be readily available or practical.

To address these limitations, alternative techniques have been proposed that require less sample volume and testing time for geometallurgical analysis. These alternative methods aim to provide comparable results to the standard Bond method with reduced resource requirements and testing time. Mwanga et al. mention one such alternative approach in the study in 2017.

In the specific case of the mentioned study, a ball mill was selected for the experiment because it was available, and the ore samples were obtained from the mine site. The ball mill is commonly used equipment for grinding and can be used to determine the Bond Work Index. Other equipment and methods, such as the stirred mill or HPGR (High-Pressure Grinding Rolls), may also be suitable for determining the work index depending on the specific circumstances and available resources.

It is important to consider the specific requirements and limitations of the study when selecting the appropriate method for measuring the Bond work index. Factors such as sample availability, time constraints, and equipment availability should be taken into account to ensure the feasibility and accuracy of the Work Index determination

3. METHODOLOGIES

3.1. Materials

Table 2: The materials required to conduct this experiment:

no	Description	uses
1	Jaw crusher	sample preparation
2	Ball/GCT/mill	run experiment
3	Gold ore(MIDROC) Lega Dembi and sakaro	run on experiment
4	Ro-tab screen with shakers	sieving
5	Stop watch	Time recording
6	Pen	writing
7	Note book	Take note
8	Weight balance	weighing
9	Sample splitter	
10	Tachometer	

Data: Mineralogical characterized data

XRF, Optical microscopy, used

3.2. Methods

3.2.1. Study Area

The Lega Dembi deposit is indeed one of the significant sources of gold in Ethiopia. Situated in the Adola granite-greenstone terrane formation in southern Ethiopia, specifically in the late Precambrian metamorphosed sediments of the Megado belt, it has been an active gold mining site since February 2, 1992. The Megado belt is characterized by its N-S trending volcano-sedimentary rocks. Besides gold, the Lega Dembi deposit is also associated with other economically valuable minerals *(Billay etal., 199,)*

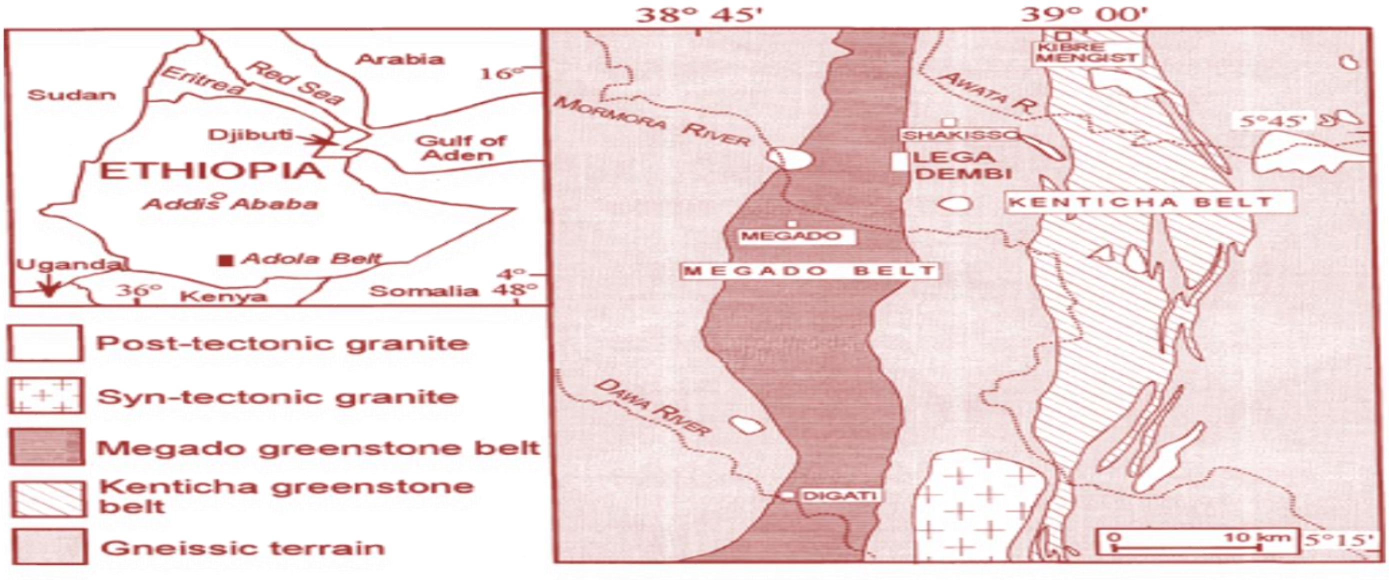


Figure 6: Simplified geological map of Location map and regional geological setting of the Adola granite-greenstone terrane in southern Ethiopia (Billay et al., 1997).

3.2.1.1. Sample Collection, Sample Quantity

Ethiopia's Lega Dembi gold mine has a long history of producing gold, but open pit mining is currently unprofitable; underground mining is still active. Based on this underground mining, Lega Dembi and sakaro ores both site 4,4samples, each weighing 5kg, to investigate grindability and comminution energy consumption.

3.2.1.2. Sample preparation and classification

In the sample preparation and classification process, the following steps were undertaken:

Ore Classification: Based on the characterized mineral associations and texture, the Lega Dembi ore was classified as having a macro-scale underground grain size of gold, classified as fine. On the other hand, the Sakaro ore was classified as having medium to coarse grains.

Initial Crushing and Screening: A total of 20 kilograms of ore samples from Lega Dembi and 20 kilograms of ore samples from Sakaro were charged into a Boyd crusher and initially screened down to 1 mm in size.

Re-Crushing: The crushed samples were then re-crushed to achieve a particle size of 100% passing through a 3.35 mm sieve. This step ensures that the particle size distribution of the samples is consistent and appropriate for further testing.

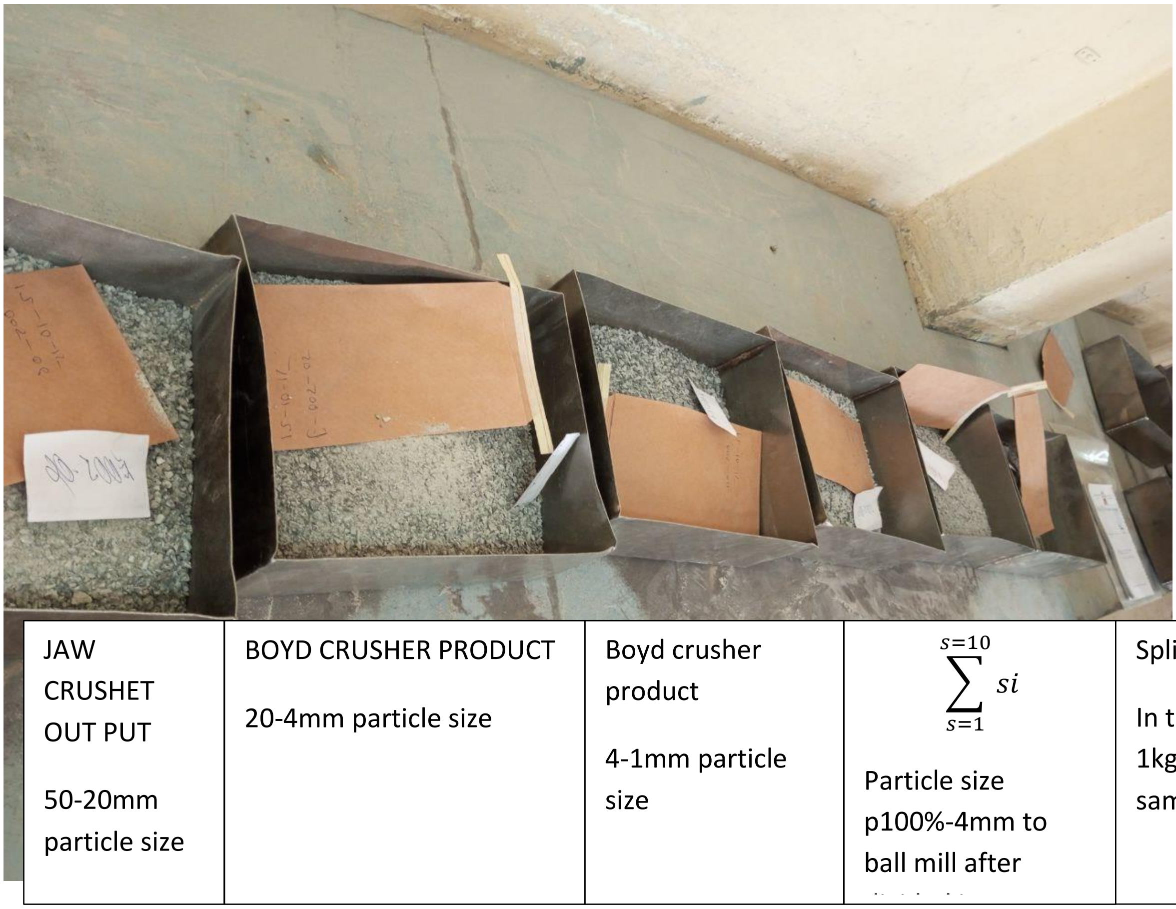
Screening and Division: All the re-crushed samples were screened to remove any particles larger than 3.35 mm. The remaining material, which had particle sizes smaller than 3.35 mm, in all sieve less than 3.35mm remained was divided into five for both deposits. This division allows for multiple test at different mill speed and grinding time conditions

Selection of Test Samples: To prepare 10 kilograms of material for run of the experiment, 5 kilogram was chosen from each site (Lega Dembi and Sakaro). This selection ensures a representative portion of the samples for testing purposes.

Pre-Quantification of Feed Size Distribution: Before charging the selected test samples to the mill, the percentage of material above and below the test sieve size of 150 microns (0.15 mm) was pre-quantified. This information helps to characterize the feed size distribution and provides important data for the grinding experiment.

By following these steps, a representative portion of the ore samples from both the Lega Dembi and Sakaro deposits was prepared for the grinding experiment. The size distribution of the samples was controlled and quantified to ensure consistency and accuracy in subsequent testing.

Prepared by Boyd crusher



JAW CRUSHET OUT PUT 50-20mm particle size	BOYD CRUSHER PRODUCT 20-4mm particle size	Boyd crusher product 4-1mm particle size	$\sum_{s=1}^{s=10} si$ Particle size p100%-4mm to ball mill after	Splitted In to 1kg sample

Figure 7: Sample preparation and classification

3.3. Research design

3.3. 1. Experimental variables

3.3.1.1. Constant variables

Ball and Mill size (Ѳ), Ball and Ore charge (J, U), Design circuit etc.

3.3.1.2. Control variables

Residence time of ore in mill(R), Rotational speed of mill ϕc)

Table 3: Experiment Design

Factors		sakaro	Lega Dembi
Residence time (R)		10	15
Mill speed (ϕc)		50%,10'	50%,10'

	40 50	60%,10'	60%,10'
	60	40%,15'	40%,15'
		60%,15'	60%,15'
		50%,15	50%,15

3.3.2. Bond Ball Mill Test

The method determining grind ability and energy consumptions by bond ball mill test.

Table 4: Mill characteristics and test conditions

Mill diameter, D (mm)			200
Steel ball size, d (mm)			20
Mill volume (dm^3)			5
Critical speed, Nc (rpm)			100
Mill speed, ϕc (% of critical)			40; 50; and 60
Ball filling, J (%)			30
Powder filling, U (%)			10
Material site: Lega Dembi and Sakaro gold ores			Dry
Ball charge weight (kg)	Ball Size	No	10
	2cm	36	
	1cm	6	
	0.5cm	4	

Size − reduced to 100% < 3.35mm (4 mesh) and about F80% < 2700 µm

For each grinding test, the mill was therefore loaded with 10kg of steel balls and 1kg of the gold ore feed sample for one run.

3.3.3. Experimental procedures:

Step 1: Calculate the mass of undersize produced per revolution:

Record the mass of undersize produced per revolution in grams.

Step 2: Perform a size analysis on the screen undersize and the original mill feed:

Obtain the weight fractions or percentages of particles in different size ranges for both the screen undersize and the original mill feed.

Step 3: Calculate the feed to product ratio:

Step 4: Estimate the energy consumption per revolution:

Calculate the mass of the material that passes the screen undersize

Divide this mass by the number of revolutions it took to produce it (the mass of undersize produced per revolution) to get the mass of undersize produced per revolution in grams.

Multiply the mass of undersize produced per revolution by the feed to product ratio to obtain the estimated energy consumption per revolution.

Bond work index rule:

Power (P) $=10W_i\left[\frac{1}{\sqrt{p}} - \frac{1}{\sqrt{f}}\right]*$ cf kwh/t, cf=1

Moreover, the energy consumed by the mill is proportional to the time (t) and is given as:

$E=P*t$

4. Result and Discussion

4.1. The textures, mineral associations, and liberation effects of grinding

It can have a significant impact on the grinding process and subsequent recovery of target minerals. Here are some key observations based on the mentioned deposits:

Fine-Grain Samples: Fine-grained samples tend to have finer feed and product sizes compared to medium and coarse-grained samples. This suggests that fine-grained material can be ground more easily and achieve the desired particle size with less grinding effort.

Mineral Associations: The mineral associations in both deposits include sulfide minerals such as pyrrhotite, pyrite, galena, chalcopyrite, and sphalerite. Non-sulfide minerals like scheelite are also present. Understanding the mineral associations are important as different minerals may have varying hardness and response to grinding, influencing the optimal grinding conditions.

Gangue Minerals: The dominant gangue minerals in the Lega Dembi deposit are quartz, biotite, phlogopite, muscovite, and magnetite. In the Sakaro deposit, the dominant gangue minerals are quartz, muscovite, biotite, and phlogopite. The presence of gangue minerals can affect the grinding behavior and efficiency, and their liberation characteristics should be considered.

Liberation Effect: The liberation of the target minerals in the Sakaro deposit appears to be relatively good, as indicated by the statement that coarse-sized gold grinding does not require fine grinding and can circulate in the ball mill unit. This suggests that the target minerals in the Sakaro deposit may already be sufficiently liberated at the coarse size fraction.

Considering these observations, it is important to assess the liberation characteristics of the target minerals in each deposit. This can be done through mineralogical analysis, liberation studies, and particle size analysis. Understanding the liberation effect can help determine the necessary grinding conditions and optimize the grinding process for maximum recovery of the target minerals.

Additionally, the presence of different gangue minerals and their association with the target minerals should be taken into account. Some gangue minerals may be more easily liberated during grinding, while others may require specific grinding conditions to achieve effective separation from the target minerals.

Overall, a comprehensive understanding of the textures, mineral associations, and liberation effects of grinding is crucial for designing an efficient grinding process that maximizes the recovery of valuable minerals while minimizing energy consumption and optimizing overall plant performance.

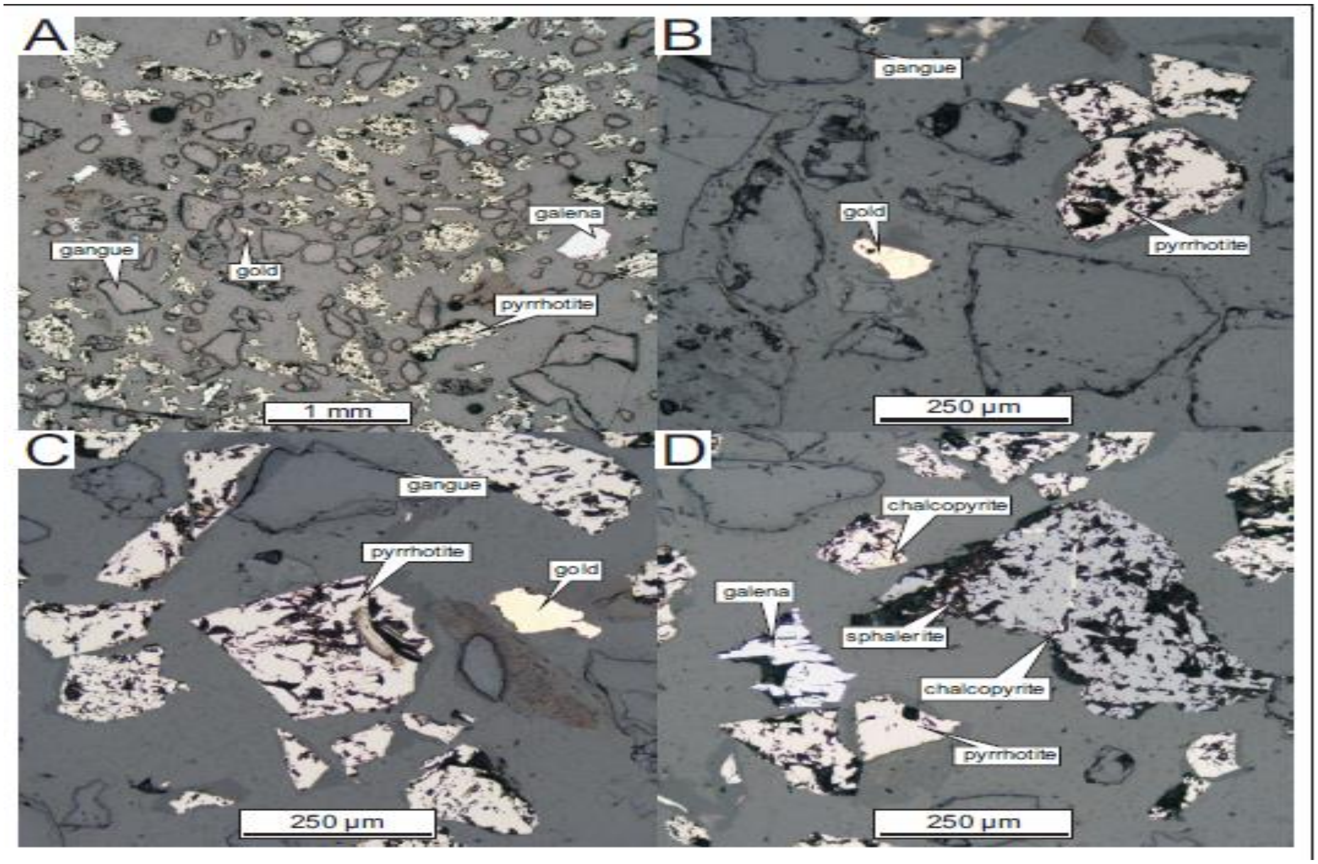


Figure 8 :A, B, C &D Sakaro sample - Plane polarized reflected light optical microscopic result, magnified by Nikon DMC1200F 13.5 megapixel camera (source metallurgical test data confidential document by MIDROC gold mine plc

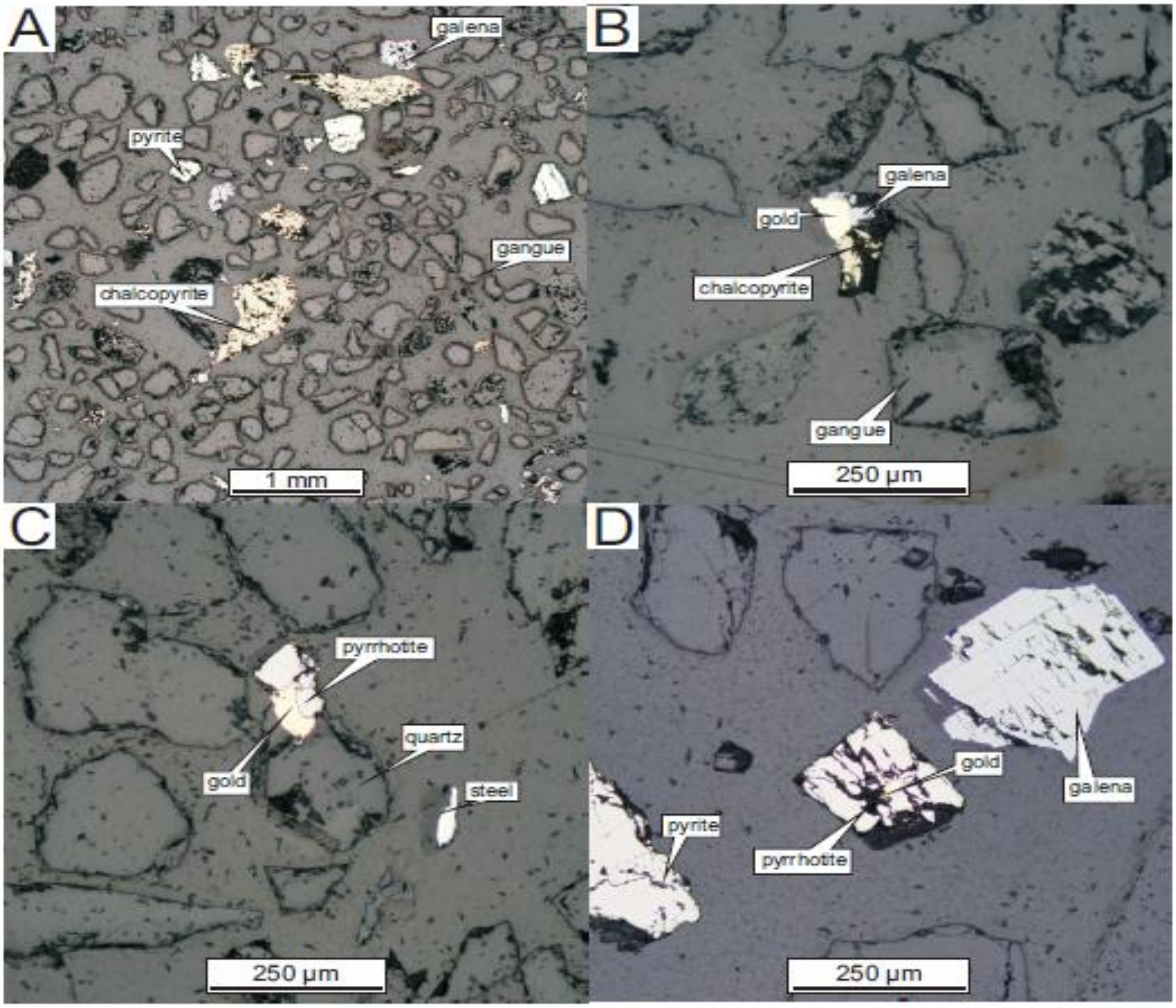


Figure 9 :Lega Dembi sample-Plane polarized reflected light optical microscopic result, magnified by Nikon DMC1200F 13.5 megapixel camera (source metallurgical test data confidential document by MIDROC gold mine plc

)

4.2. Grinding tests Gold Ore samples

Table 5: percent of desired particle class of both deposits

Test sieve :150µm			
		%of Grind ability <150µm in g/kwm minute	%of Grind ability <150µm in g/kwm minute
%product <150µm			
Cycle		Sakaro deposit	Lega Dembi deposit
1	50%,10'	25.44	33.4
2	60%,10'	32.16	39.56
3	40%,15'	25.98	42
4	60%,15'	56.3	56.64
5	50%,15	40.66	50.1

Based on the provided information, it appears that there are some differences and observations regarding the grind ability and the impact of mill speed and grinding time on the two deposits (Lega Dembi and Sakaro). Here are some key points to consider:

Comparison of mill speed: From the comparison of Cycles 1 and 2, it is indicated that there is no discernible difference between the two deposits as the mill speed is increased. This suggests that both deposits respond similarly to changes in mill speed in terms of achieving the desired particle size. The differences in desired size grams (∆7.96g and ∆7.4g) are relatively small, indicating similar grind ability at different mill speed (0.56g)

Comparison of Grinding Time: The comparison of Cycles 1 and 5 shows that there is a noticeable difference with respect to mill speed in desired size grams (∆7.96g and ∆9.44g) as the grinding time increases. This implies that the grinding time has a more significant effect on achieving the desired particle size compared to mill speed for both deposits (1.48g).

Grind Ability and Bond Work Index: The experiment demonstrates that Lega Dembi deposit has higher grind ability compared to Sakaro deposit. Additionally, Lega Dembi deposit has a lower Bond Work Index, which is an indicator of grinding efficiency. These findings suggest that Lega Dembi deposit is more easily ground to the desired particle size compared to Sakaro deposit.

Table 6: PSD p80 passing of both deposits

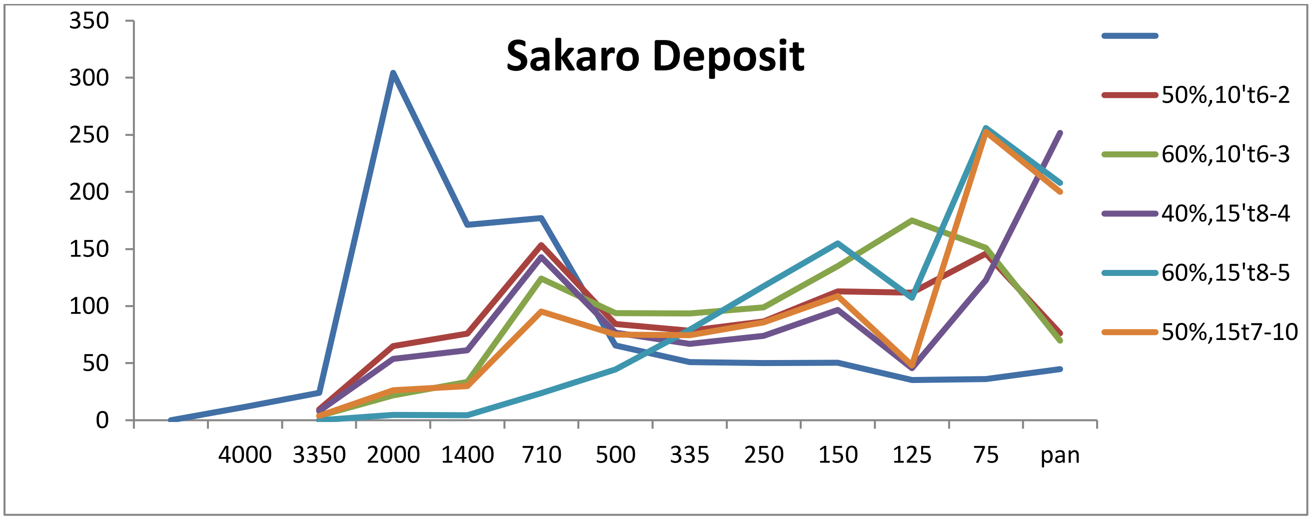
Weight of feed	1000g		P80 passing size				
Weight of feed %<150µm	11.61		F80 P80 sakaro		2700 µm	F80 P80 Lega dembi	2700µm
Weight of product	35.9				481µm		618
cycle		Weight of new feed(g)	P<150 µm	p>15µm		P<150µm	P>150µm
1	50%,10'	1000	334	666		254.4	745.6
2	60%,10'	1000	395.6	604.4		321.6	678.4
3	40%,15'	1000	420	580		259.8	740.2
4	60%,15'	1000	571.2	428.8		563	437
5	50%,15	1000	501	499		406.6	593.4

From this data bond work index calculated as

$wi = \frac{44.5}{481^{0.23} x\ 1.023^{0.82} \frac{10}{481^{0.5}} - \frac{10}{2700^{0.5}}}$=18.5kwh/t (sakaro)

WI=$\frac{44.5}{618^{0.232} x 1.123^{0.822} \frac{10}{618^{0.5}} - \frac{10}{2700^{0.5}}}$=13.5kwh/t (Lega Dembi)

Sakaro Deposit						
s/ s(µm)	Feed	50%,10'	60%,10'	40%,15'	60%,15'	50%,15'
4000	11.7	0	0	0	0	0
3350	24	9.4	3.8	8	0	3.8
2000	304.32	65	21.8	53.6	4.8	26.2
1400	171.28	75.8	33.6	61.4	4.4	29.8
710	175.2	153.4	124	142.8	23.6	95.2
500	63.64	84.2	93.8	76.8	44.4	75
335	50.84	78.4	93.4	67	79.2	74.6
250	44	86.6	98.8	73.8	117.4	85.8
150	50.44	112.8	135	96.6	155	108.6
125	34.2	111.8	175	45.6	107.2	68.2
75	30	146	151	122.7	256	232.6
-75	40	76.2	69.6	251.7	208	200.2
Total<150µm	104.2	334	395.6	420	56.64	501
%<150µmss	11.61	33.4	39.56	42	56.64	50.1



F**igure 10:**:percent of desired particle size class pass <150µm Sakaro deposit

According to this data, operating the grinding at the speed of 60-mill speed, 50-mill speed, and 40-mill speed for the same 15-minute grinding period has no discernible change on grind ability.

Lega Dembi deposit						
sieve in µm sieve size	Feed	50%,10'	60%,10'	40%,15'	60%,15'	50%,15'
4000	11.7					
3350	24	8.8	2.2	6.6		
2000	304.32	18	12.4	52.4	2	2.6
1400	171.28	30.8	15.4	55.6	2	10.2
710	175.2	44	78	146.2	13.4	31.8
500	63.64	107	106.4	110	42	43.8
335	50.84	132	131.2	108.2	57.8	57.2
250	44	200	154.2	126.2	188	144
150	50.44	168	178.6	135	131.8	137.2
125	34.2	120.4	82.2	60.2	263	264
75	30	115	168	138.4	194	184
-75	40	56	71.4	61.2	106	113.6
Total<150µm	104.2	291.4	321.6	259.8	563	561.6
%<150µm seive size	11.61	29.14	32.16	25.98	56.3	56.16

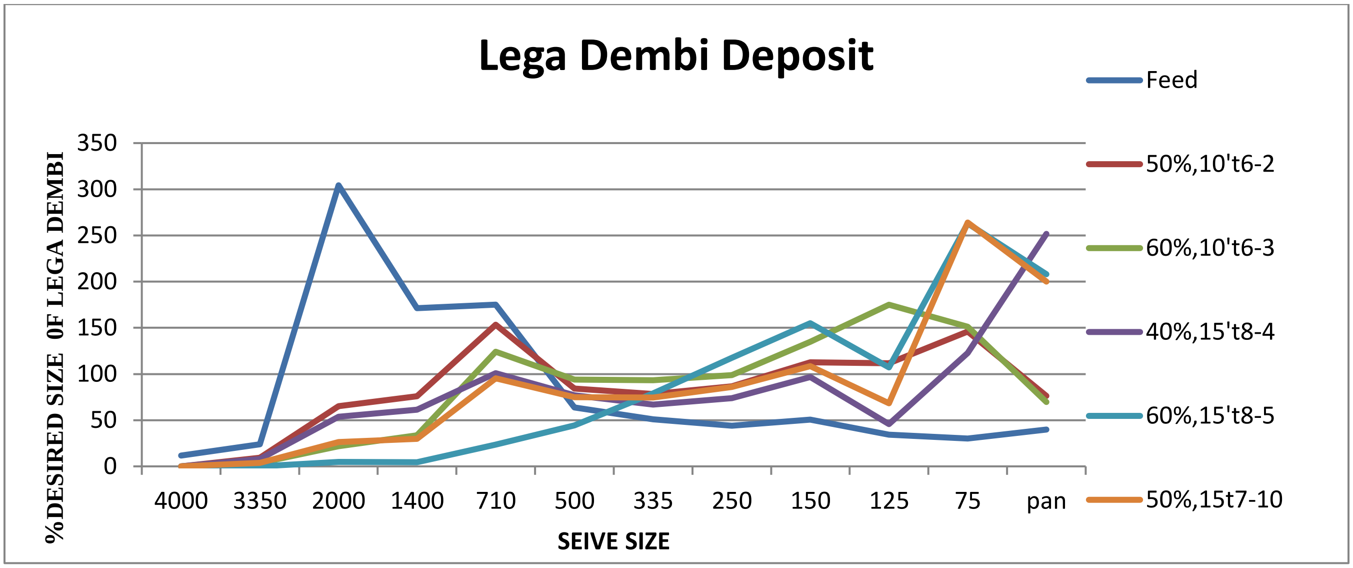


Figure 10: percent of desired particle size class pass <150μm Lega Dembi deposit

This graph shows that grinding at speeds of 60% mill speed, 50% mill speed, and 40% at grinding times of 15 minutes has no effect on the ability to grind in particular. In light of this information, grinding time rather than mill speed affects both deposits.

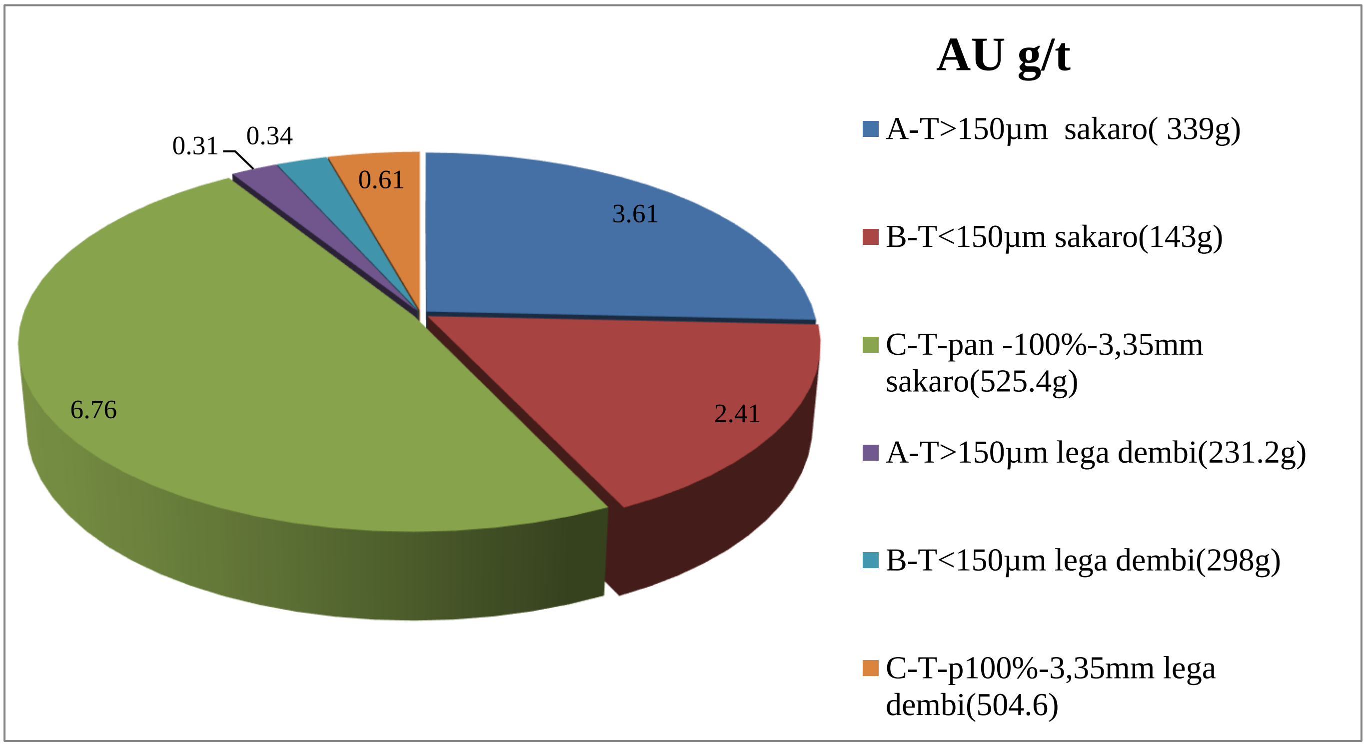


Figure 11: Assay result of both deposits

In contrast to 50.8% in the Lega Dembi deposit, 53.4% of the gold concentration in the Sakaro deposit is above test sieve. Based on the large proportion of desired particle size class in the Lega Dembi deposit, the gold grain in the Sakaro deposit is coarser than the Lega Dembi deposit. and low percentage in the sakaro deposit.

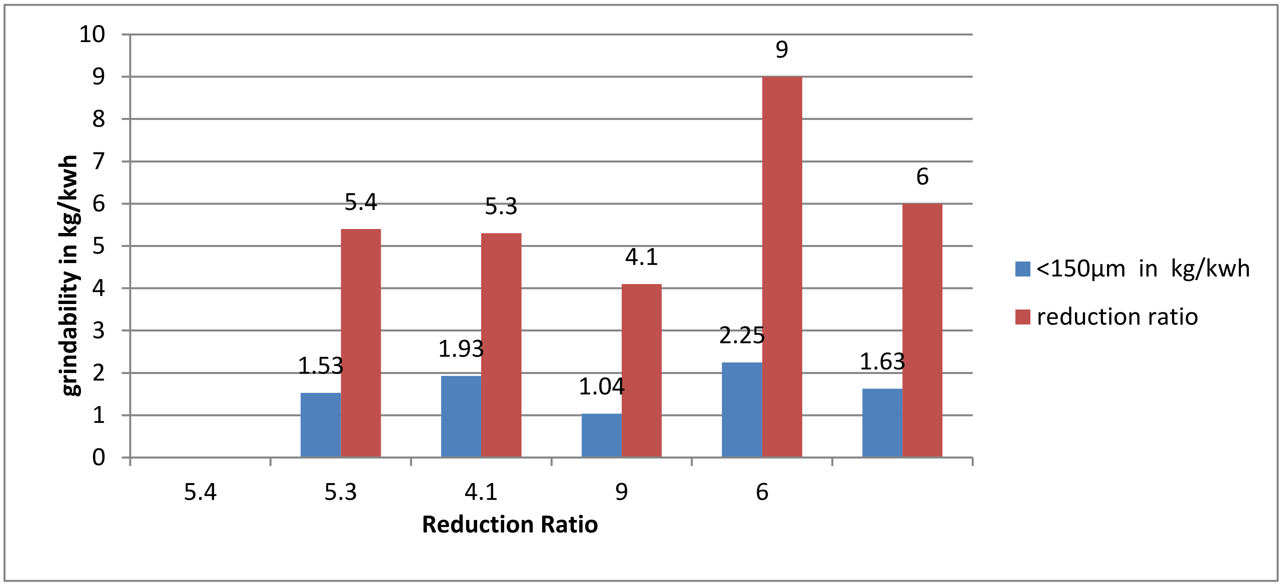


Figure 12: Grindablity vs. reduction ratio of sakaro deposit

Samples with high reduction ratio have higher grind ability at mill speed 60%, and grinding time 15', sakaro ore has nine reduction ratio and 2.25kg/kWh grindability.

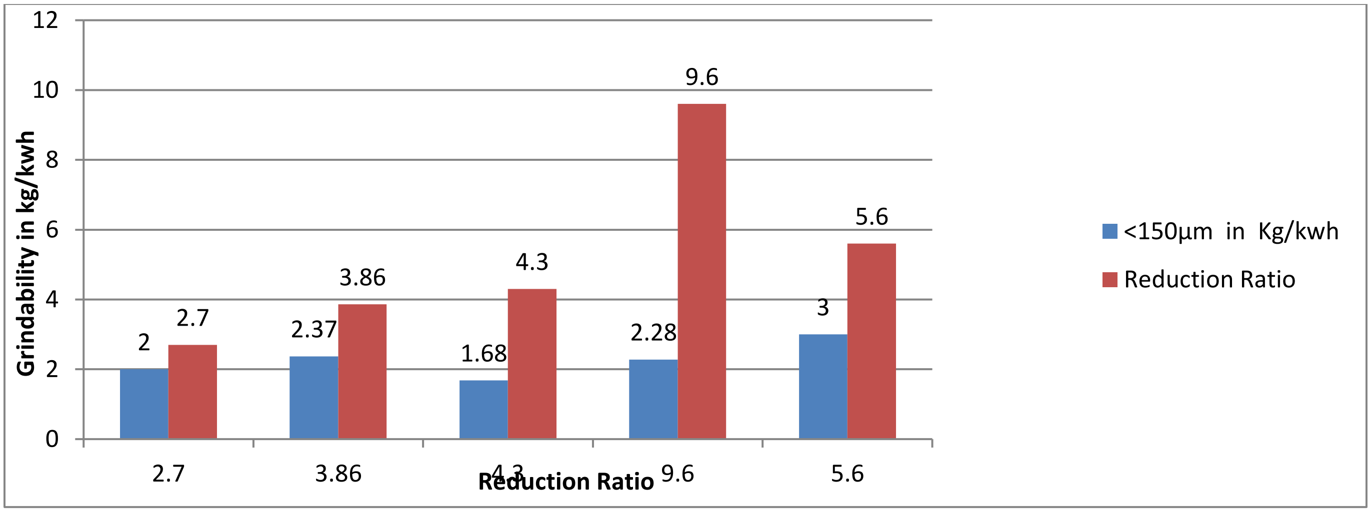


Figure 13 grindablity vs. reduction ratio of Lega Dembi deposit

Samples with high reduction ratio have higher grind ability at mill speed 60%, and grinding time 15’Lega. Dembi ore has nine point six-reduction ratio and 2.28/kWh grindability

By comparison, of both deposit sakaro deposit requires high energy with respect of Lega Dembi deposit

Table 7: grind ability and energy consumption of deposits

s/n		50%,10'	60%,10'	40%,15'	60%,15'	50%,15
Lega dembi	kwh/t	1.67	2.5	2.78	5.5	3.56
	E(w)	16.7	25	27.8	55	35.6
sakaro	kwh/t	4.7	4.67	3.69	7.12	5.16
	E(w)	47	46.7	36.9	71.2	51.6

The Lega Dembi deposit exhibits a relatively high desired grain size mass and a low energy requirement compared to the Sakaro deposit .The experimental grinding of a particular ore is advised based on this equation model's relatively high desired grain size mass and low energy requirement. Based on the data obtained, the Sakaro deposit requires high energy to discharge product from the ball mill because the coarse gold grain needs to be minimized in size to operate in the same plant.

5. Conclusion and Recommendation

5.1.Conclusion

Based on the comparison of grindability and comminution energy consumption between the Sakaro and Lega Dembi deposits, the following conclusions can be drawn:

Grindability and Energy Consumption: The fine-grained material from the Lega Dembi deposit exhibits higher grindability and lower energy consumption compared to the medium- and coarse-grained material from the Sakaro deposit. This suggests that the Lega Dembi deposit can be ground more easily and efficiently.

Production of Fines: The fine-grained material from the Lega Dembi deposit produces more fines compared to the medium and coarse-grained samples from the Sakaro deposit. This indicates that the Lega Dembi deposit has a higher propensity to generate smaller-sized particles during grinding.

Mill Speed and Grinding Time: The Lega Dembi deposit demonstrates high grindability at low mill speeds, given equal grinding time. This implies that the Lega Dembi deposit can achieve the desired particle size more efficiently with lower mill speeds compared to the Sakaro deposit.

Unique Plant Design: To maximize the performance of each deposit, it is recommended to create a unique plant design tailored to the specific characteristics of each deposit. This design should consider the optimal mill speed, grinding time, and other parameters to achieve efficient grinding and desired particle size.

Energy Conservation: To conserve energy, a mill speed of 40 rpm for 15 minutes is preferred, although this may result in a compromise in mill performance. This suggests that a balance needs to be struck between energy conservation and achieving the desired grind size.

Consideration for Combined Plant Operation: If both deposits were treated in the same plant, it would require running the mill at high speeds and for extended periods. However, this approach may not be energy-efficient and should be carefully evaluated, taking into account the gold grade in the ore.

Processing of Sakaro Deposit: In the case of the Sakaro deposit, the gold grain would circulate in a closed circuit cyclo-sizer underflow of a ball mill to achieve the appropriate plant design discharge size for downstream processing tanks.

5.2.Recommendation and future work

Increase the number of small balls and ball coverage: The author of the paper used balls of various sizes dominated by coarse size balls. To improve the milling process, it is recommended to increase the number of small balls and increase the percentage of ball coverage. This adjustment can help enhance the grinding efficiency and reduce particle size effectively.

Separate processing of both deposits: It is advised to process both deposits in separate plants. By doing so, you can optimize the processing conditions and tailor them specifically to each deposit's characteristics. This approach allows for better control over the processing parameters and can lead to improved recovery rates and overall operational efficiency.

C**onsider running both deposits in the same plant (Optimization)** : If separate processing plants are not feasible, an alternative approach is to run both deposits in the same plant. In this case, it is recommended to operate the plant at 40% critical speed and residence time 15 minutes running the plant.

Investigate alternative grinding technologies: Explore other grinding technologies and equipment that may offer advantages over the current ball mill setup. Technologies such as high-pressure grinding rolls (HPGR) or vertical roller mills (VRM) could be assessed for their suitability in improving efficiency and reducing energy consumption.

Circuit: This experiment done in the batch ball mill circuit, I recommend to run experiment in continuous circuit to perform efficiency.

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7. Appendices

Lega Dembi Deposit						
seive in µm seive size	Feed	50%,10'	60%,10'	40%,15'	60%,15'	50%,15'
4000	11.7					
3350	24	8.8	2.2	6.6		
2000	304.32	18	12.4	52.4	2	2.6
1400	171.28	30.8	15.4	55.6	2	10.2
710	175.2	44	78	146.2	13.4	31.8
500	63.64	107	106.4	110	42	43.8
335	50.84	132	131.2	108.2	57.8	57.2
250	44	200	154.2	126.2	188	144
150	50.44	168	178.6	135	131.8	137.2
125	34.2	120.4	82.2	60.2	263	264
75	30	115	168	138.4	194	184
-75	40	56	71.4	61.2	106	113.6
Total<150µm	104.2	291.4	321.6	259.8	563	561.6
%<150µm seive size	11.61	29.14	32.16	25.98	56.3	56.16

Appendix1: desired particle size <150µm Lega Dembi Deposit

Sakaro Deposit						
s/ si(µm)	Feed	50%,10'	60%,10'	40%,15'	60%,15'	50%,15'
4000	11.7	0	0	0	0	0
3350	24	9.4	3.8	8	0	3.8
2000	304.32	65	21.8	53.6	4.8	26.2
1400	171.28	75.8	33.6	61.4	4.4	29.8
710	175.2	153.4	124	142.8	23.6	95.2
500	63.64	84.2	93.8	76.8	44.4	75
335	50.84	78.4	93.4	67	79.2	74.6
250	44	86.6	98.8	73.8	117.4	85.8
150	50.44	112.8	135	96.6	155	108.6
125	34.2	111.8	175	45.6	107.2	68.2
75	30	146	151	122.7	256	232.6
-75	40	76.2	69.6	251.7	208	200.2
Total<150µm	104.2	334	395.6	420	56.64	501
%<150µmss	11.61	33.4	39.56	42	56.64	50.1

Appendix 1: desired particle size <150µm Sakaro Deposit

	A-T>150µm sakaro	3.61	339
	B-T<150µm sakaro	2.41	143
sample from Sakaro	C-T-pan -100%-3,35mm sakaro	6.76	525.4
	C-T>150µm lega dembi	0.31	231.2
	C-T-p100%-3,35mm lega dembi	0.61	298
mple from Lega Dem	C-T<150µm lega dembi	0.34	504.6

Appendix 2: result of fire assay of both deposits

EXPERIMENTAL CON	f80 27000µn	p80 in micron	<150µm in kg/kwh	reduction ratio
SAKARO				
50%,10't1	27000µm	500µm	1.53	5.4
60%,10't3-6	27000µm	505µm	1.93	5.3
40%,15't3-7	27000µm	650µ	1.04	4.1
60%,15't4-8	27000µm	300µm	2.25	9
50%,15t4-9	27000µm	450µM	1.63	6

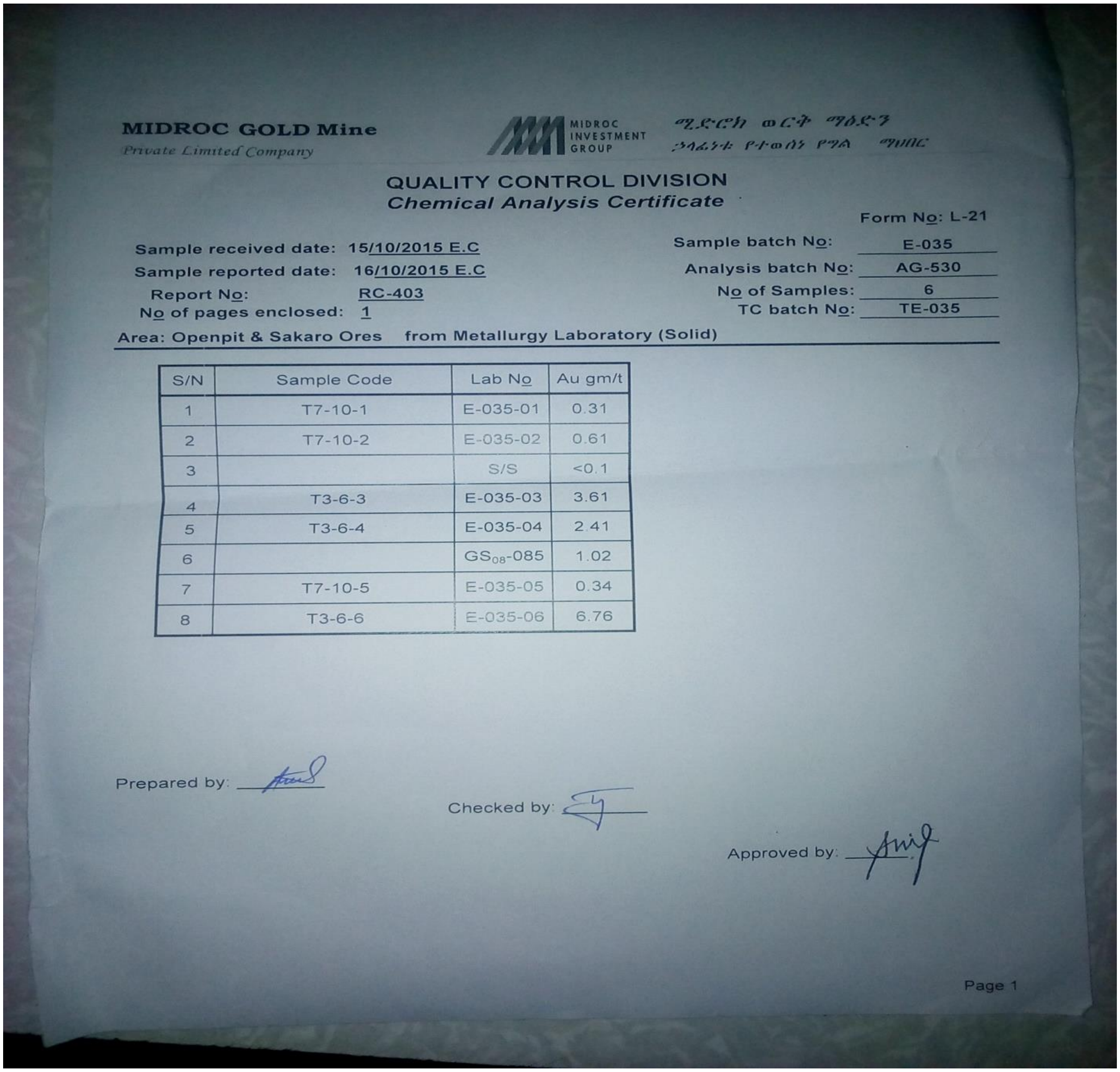
Appendex 3: grind ability vs. reduction ratio of sakaro deposit

LEGA DEMBI				
EXPERIMENTAL CON	f80 27000µn	P80 in micron	<150µm in g/kwh	Reduction Ratio
50%,10't1	27000µm	1000	2	2.7
60%,10't3-6	27000µm	700	2.37	3.86
40%,15't3-7	27000µm	630	1.68	4.3
60%,15't4-8	27000µm	280	2.28	9.6
50%,15t4-9	27000µm	480	3	5.6

Appendix 4: grind ability vs. Reduction ratio of Lega Dembi deposit

s/n		50%,10'	60%,10'	40%,15'	60%,15'	50%,15
Lega dembi	kwh/t	1.67	2.5	2.78	5.5	3.56
	E(w)	16.7	25	27.8	55	35.6
sakaro	kwh/t	4.7	4.67	3.69	7.12	5.16
	E(w)	47	46.7	36.9	71.2	51.6

Appendex 5 grind ability And Energy Consumption of Both deposit



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Private Limited Company

MIDROC
INVESTMENT
GROUP

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QUALITY CONTROL DIVISION
Chemical Analysis Certificate

Form No: L-21

Sample received date: 15/10/2015 E.C
Sample reported date: 16/10/2015 E.C
Report No: RC-403
No of pages enclosed: 1

Sample batch No: E-035
Analysis batch No: AG-530
No of Samples: 6
TC batch No: TE-035

Area: Openpit & Sakaro Ores from Metallurgy Laboratory (Solid)

S/N	Sample Code	Lab No	Au gm/t
1	T7-10-1	E-035-01	0.31
2	T7-10-2	E-035-02	0.61
3		S/S	<0.1
4	T3-6-3	E-035-03	3.61
5	T3-6-4	E-035-04	2.41
6		GS_{08}-085	1.02
7	T7-10-5	E-035-05	0.34
8	T3-6-6	E-035-06	6.76

Prepared by:

Checked by:

Approved by:

Page 1

Appendix 6: fire assay result of both deposits at different test sieve sample