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EFFECT OF VARIOUS GRINDING MECHANISMS DURING PARTICLE PRODUCTION

by

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DECLARATION

I hereby declare that I have conducted, completed the research work and written the dissertation entitled “The Effect of Grinding Mechanisms During Particle Production”. I also declare that it has not been previously submitted for the award of any degree or diploma or other similar title of this for any other examining body or University.

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LIST OF SYMBOLS

Kg	Kilogram
m	Metre
mm	Millimetre
Wt%	Weight percent
p80	Passing percent (80%)
p50	Passing percent (50%)
p20	Passing percent (20%)
p10	Passing percent (10%)
%	Percentage
g	Gram

LIST OF ABBREVIATIONS

SEM	Scanning Electron Microscope
PSD	Particle Size Distribution
BPR	Ball to Powder Ratio
RPM	Rotational Per Minute

KESAN PELBAGAI MEKANISME PENGISARAN SEMASA PENGELUARAN PARTIKEL

ABSTRAK

Terdapat beberapa jenis mesin pengisar yang digunakan dalam industri seperti pengisar bebola, pengisar planet, pengisar jet, pengisar kacau dan pengisar cincin. Mesin-mesin pengisar berkongsi tujuan yang sama iaitu mengurangkan saiz sampel. Selain itu, dalam proses pengisaran, terdapat beberapa mekanisme yang wujud iaitu impak dan lelasan. Mekanisme tersebut boleh dimanipulasi kerana ia berbeza dengan parameter operasi. Dua jenis sampel telah digunakan dalam eksperimen ini iaitu batu kapur dan granit. 20kg setiap sampel telah dihancurkan dengan penghancur rahang dan penghancur kon. Kemudian, sampel-sampel tersebut menjalani beberapa mesin pengisaran dengan parameter operasi yang berbeza. Keputusan yang diperoleh menunjukkan bahawa pengisar bebola dan pengisar planet pada kelajuan putaran tinggi, mekanisme impak akan menjadi dominan, manakala pada kelajuan putaran rendah, mekanisme lelasan lebih dominan. Untuk saiz yang berbeza dari media pengisaran untuk kilang bola, bola keluli 45mm menunjukkan bahawa ia dapat mengurangkan bahan yang lebih kasar tetapi bola keluli 27mm menunjukkan bahawa bahan saiz yang lebih kecil digiling dengan cekap. Untuk bilangan bola atau BPR yang berlainan, menunjukkan bahawa 10: 1 BPR menghasilkan mekanisme impak manakala 3:1 BPR memberikan mekanisme lelasan. Untuk pengisar cincin, ia menghasilkan produk yang sangat halus dalam masa yang singkat kerana intensiti tinggi impak dan lelasan. Selain itu, untuk jenis mesin yang berbeza, pengisar bebola menghasilkan pengagihan saiz yang lebih luas jika dibandingkan dengan pengisar planet dan cincin. Untuk jenis sampel yang berbeza, granit sukar dikisar berbanding batu kapur kerana kekuatan yang lebih tinggi.

EFFECT OF VARIOUS GRINDING MECHANISMS DURING PARTICLE PRODUCTION

ABSTRACT

There are several types of grinding machines that were used in industry such as ball mill, planetary mill, jet mill, stirred mill and ring mill. These machines share the same purpose that is to reduce the size of a sample. Moreover, in a grinding process, mechanisms of grinding like impact and abrasion took place. These mechanisms can be manipulated as it varies with operating parameter. Two types of samples were used in this experiment that is limestone and granite. 20kg of each sample were crushed with jaw crusher and cone crusher. Then, the samples undergoes several grinding machines with different type of operating parameter. The grinding machine used were ball mill, planetary mill and ring mill. The results obtained show that ball mill and planetary mill at high rotational speed, the impact mechanism will be dominant, whilst at low rotational speed, the abrasion mechanism is more dominant. For different size of grinding media for ball mill, 45mm steel ball shows that it can reduce coarser material but 27mm steel ball shows that smaller size material are grind efficiently. For different number of ball or BPR, shows that 10:1 BPR produce impact mechanisms while 3:1 BPR gives abrasion mechanism. For ring mill, it produces very fine product in a short time due to high intensity of impact and abrasion. Moreover, for different type of machine, ball mill produces much wider size distribution if compared to planetary and ring mill. For different type of sample, granite are hard to grind compared to limestone due to higher strength.

CHAPTER 1

INTRODUCTION

1.1 Introduction

Grinding is the last stage of comminution process. Grinding is a very important process in mineral processing. There are several types of grinding machines are used in industries such as rod mill, ball mill, ring mill, planetary mill and jet mill. These grinding machines shares the same objective and purpose, that is to reduce size of material produced by crushers machine. The material will undergo size reduction and produce smaller pieces or powder form of material.

Fine particles are a very important aspect used in industries nowadays. The size of fine particle is about 1 to 32 µm. Furthermore, fine particles are used widely in industries and have their own specification of fine particles depends on their products. Industries like cosmetic, ceramic, pharmaceutical, fine chemical, paint, plastic and food have high demand of these fine particles.

Moreover, finely ground mineral also used as a filler in cement industries in order to accelerate cement hydration rate. This shows that the needs of finely ground mineral are high from days to days. The fine mineral must be grind to achieve specific properties and to become a filler in its own industry. For example, the efficiency of catalyst, quality of cosmetic product, quality of pharmacy product depends on shape of particle, particle size distribution and the present of polymorph (Varinot *et al.,* 1997).

These types of grinding machines have different type of mechanisms which will produce different type of fine particles. Some of the grinder may produce certain sizes of fine particle and maybe have its limit. There are lots of uses of fine particles and the most important part to be consider is size and type of the fine particle used. This is because different type of product uses different size and type of fine particle. Plus, by using the right size and type of fine particle will reduce cost and increase the efficiency of a product. Hence, this study shall aid in the selection of grinder to produce a certain type and size of fine particle.

1.2 Problem Statement

Comminution process is a process of reduction of particle to a smaller size particle. It consists of three general classes that is primary, secondary and tertiary reduction process. In this project, the topic about fine particle is covered and it is generally at the secondary or tertiary classes (grinding). Grinding process are the process to produce much finer particle than crushing process. There are several grinding machines such as ball mill, ring mill and jet mill and each of the grinding machine have different mechanism which produce different type and size of fine particle.

Nowadays, grinding process is a must in making powder or any other fine particles. For example, fine particles are widely used in industries as a filler which have a certain effect on their product. Plus, iron ore grade can be improve in magnetic separation by using finer particles (Erdem and Ergün, 2009). In order to have an optimum and efficient process, the right size or type of fine particle must be used. This lead to the question of whether it is capable to determine which grinding machines produces which type or size of fine particle. What are the characteristic of fine particle produce by different type of grinding machine.

Moreover, are there any limitation in sizes produce by a certain grinding machine? This study will aid in the selection of grinder to produce certain product. It will reduce the cost and increase the efficiency of a product.

1.3 Objectives

Objectives of this research are as follows:

I. To evaluate the product produced using various grinding parameter (rotational speed, grinding media size, number of ball).

II. To differentiate the product between the grinding machines.

III. To relate the product produced by material that have different strength.

1.4 Research Scope

In this project, the product produced by various grinding mechanisms will be evaluated. Two types of mineral will be tested that is granite and limestone. The samples come in large form that need to be breakdown first by a hammer. Then, the samples will undergo crusher and will be characterized physically by using particle size distribution and by observation. Both type of sample will undergo several types of grinding machines. Then the product will be evaluated by using particle size distribution and morphology analysis.

1.5 Thesis Outline

In chapter 1, presents the introduction, objectives, problem statement and research scope of present work.

In chapter 2, literature reviews are about the information of particle breakage, the needs of this project, and the breakage mechanisms and operation of grinding machines like ring mill, ball mill, planetary mill and jet mill. The operating parameters that affect or create a certain type of mechanisms and how it affect the product.

In chapter 3, the methodology is represented, including sample preparation, step by step procedure, particle size analysis and morphology analysis.

In chapter 4, the results are obtained and discussed. These were the result of characterization of samples, particle size distribution of feed, particle size analysis of ground product and morphology analysis.

In chapter 5, the conclusion and suggestion for future work are made for this project.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

Comminution is the earliest stage of mineral processing which consists of crushing and grinding process. Because of the ore and gangue mineral are associated together, they need to be liberated or separated in order to proceed for the next process. Grinding is the last stage of comminution process which produces fine products for up to 300 µm. By this stage, a combination of abrasion and impact are applied in order to reduce the size of particles (Wills and Napier-munn, 2006). A grinding mill is a unit operation designed to break a solid material into smaller pieces. There are many different types of grinding mills and many types of materials processed in them. Historically, mills were powered by hand (mortar and pestle), working animal, wind (windmill) or water (watermill).

There are several mechanisms that occurs inside an operating grinding mills such as abrasion, impact, attrition and chipping. These mechanisms occurs at the same time inside an operating grinding machines. Moreover, these mechanisms become dominant if a certain operating variable is manipulated. These actions will affect the production of particles. Furthermore, there are several grinding machines that is used such as ball mill, planetary mill and ring mill. Each grinding machines provides different type of processing action which will result in different particle production.

2.2 Granite

Granite is an igneous rock that form from the slow crystallization of magma underneath the Earth's surface. It is light-colored igneous rock that consists of large grain that visible with naked eyes. Furthermore, it is have the composition of feldspar and quartz and minor amount of amphiboles, mica and other minerals. This mineral composition usually gives granite a red, pink, gray, or white color with dark mineral grains visible throughout the rock.

2.2.1 Application

Granite is often use as construction and other application as it have a high strength. Granite are used as mixture in asphalt making, buildings, monument, paving and other exterior work.

Granite is the rock most often quarried as a "dimension stone" (a natural rock material that has been cut into blocks or slabs of specific length, width, and thickness). Granite is hard enough to resist abrasion, strong enough to bear significant weight, inert enough to resist weathering, and it accepts a brilliant polish. These characteristics make it a very desirable and useful dimension stone. Granite is a commonly used as an ornamental stone as well as a building material. India is one of the leading nations in the production and export of granite and other stones, with about 110 varieties of different colours and textures. As the physical and chemical properties of granite are suitable, the by-product rock wastes could be used for the preparation of concrete as a partial replacement for fine or coarse aggregates (Sharma et al., 2017).

Granite is also used as a crushed stone or aggregate. In this form it is used as a base material at construction sites, as an aggregate in road construction, railroad ballast, foundations, and anywhere that a crushed stone is useful as fill. Moreover, granite has been used for thousands of years in both interior and exterior applications. Rough-cut and polished granite is used in buildings, bridges, paving, monuments, and many other exterior projects. Indoors, polished granite slabs and tiles are used in countertops, tile floors, stair treads, and many other practical and decorative features.

2.3 Limestone

Limestone is a sedimentary rock composed primarily of calcium carbonate ($CaCO_3$) in the form of the mineral calcite. It most commonly forms in clear, warm, shallow marine waters. It is usually an organic sedimentary rock that forms from the accumulation of shell, coral, algal, and fecal debris. It can also be a chemical sedimentary rock formed by the precipitation of calcium carbonate from lake or ocean water.

2.3.1 Application

Firstly, limestone is used as dimension stone. Limestone is often cut into blocks and slabs of specific dimensions for use in construction and in architecture. It is used for facing stone, floor tiles, stair treads, window sills, and many other purposes. It is also used as roofing granules where it is crushed to a fine particle size, crushed limestone is used as a weather and heat-resistant coating on asphalt-impregnated shingles and roofing. It is also used as a top coat on built-up roofs. Moreover, limestone is used as flux stone. Crushed limestone is used in smelting and other metal refining processes. In the heat of smelting, limestone combines with impurities and can be removed from the process as a slag.

For Portland cement, limestone is heated in a kiln with shale, sand, and other materials and ground to a powder that will harden after being mixed with water. Furthermore, limestone is also used as lime. Calcium carbonate is one of the most cost-effective acid-neutralizing agents. When crushed to sand-size or smaller particles, limestone becomes an effective material for treating acidic soils. It is widely used on farms throughout the world. If calcium carbonate ($CaCO_3$) is heated to high temperature in a kiln, the products will be a release of carbon dioxide gas (CO_2) and calcium oxide (CaO). The calcium oxide is a powerful acid-neutralization agent. It is widely used as a soil treatment agent (faster acting than Ag lime) in agriculture and as an acid-neutralization agent by the chemical industry. Nevertheless, preliminary studies showed that the long-term deformation of concretes made of limestone-rich cements are strongly dependent on the chemical-mineralogical properties of the used ground limestone as main cement component (Rezvani and Proske, 2017).

Moreover, limestone is also used for animal feed filler. Chickens need calcium carbonate to produce strong egg shells, so calcium carbonate is often offered to them as a dietary supplement in the form of "chicken grits." It is also added to the feed of some dairy cattle who must replace large amounts of calcium lost when the animal is milked. Furthermore, limestone is used in mines as safety dust, also known as "rock dust." Pulverized limestone is a white powder that can be sprayed onto exposed coal surfaces in an underground mine. This coating improves illumination and reduces the amount of coal dust that activity stirs up and releases into the air. This improves the air for breathing, and it also reduces the explosion hazard produced by suspended particles of flammable coal dust in the air.

2.4 General Grinding Machines

There are several grinding machines that are used in industries nowadays. Generally, grinding mills are classified into two type that is tumbling mill and stirred mill. In this project, ring mill, ball mill and planetary mill are used.

First and foremost, tumbling mill is a machine that pulverizes or grinds material inside it by using grinding medium such as steel ball, steel rod, ceramic or rubber. Furthermore, the machine rotates at its horizontal axis and usually used in the mineral processing industries as coarse grinding process. The size of course material can be reduced from 5 – 250 mm to 40 – 300 µm (Wills and Napier-munn, 2006).

On the other hand, stirred mill operation are applied in a finer process, which is about 15 – 40 µm and ultra-fine (less than 15 µm). A stirred mill is a machine consists of either horizontal or vertical stationary mill shell. In addition, a stirrer inside the mill operate by agitating the fine particles inside the mill.

(Chauruka *et al.*, 2015) stated that product of particles size less than 1mm in diameter can be achieved with grinding mills like vibratory mills, ball mills, rod mills and jet mills. However, for ultrafine dry milling, the grinding machines that are usually used are planetary ball milling, vibratory ball milling and air jet milling are commonly used. In these mills particle size is reduced by impact, shear, attrition or compression or a combination of them. Figure 2.1 shows an array of size reduction equipment available for different combinations of feed and product particle sizes.

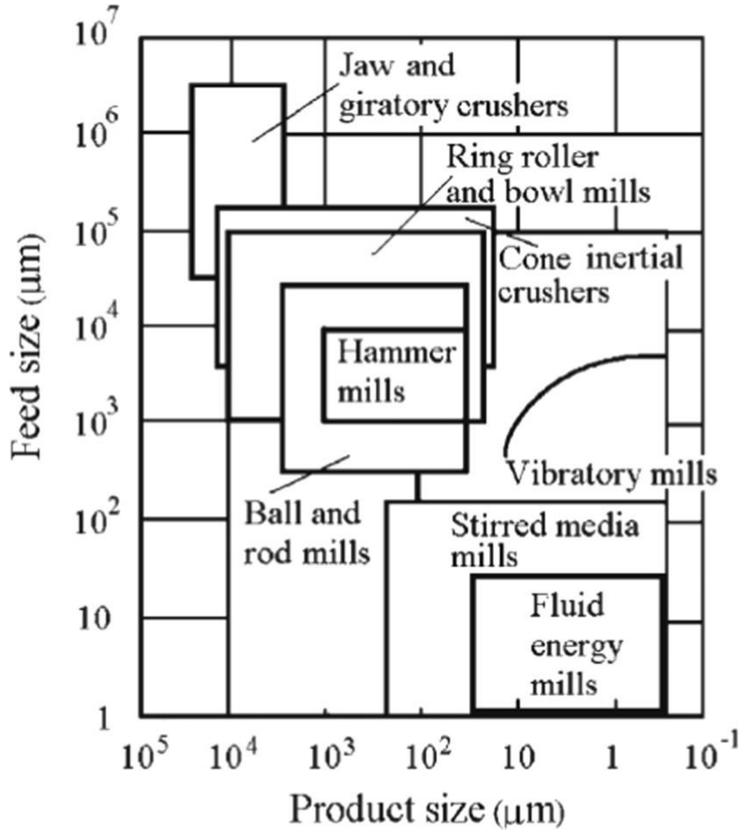

Figure 2.1: Size reduction equipment available for different combinations of feed and product particle sizes (Chauruka *et al.*, 2015).

2.5 Breakage Mechanism in Tumbling Mill

As opposed to crushing, grinding is subjected to law of probability and a more random process. Moreover, the process of grinding by tumbling mill are affected by motion type, size, volume or quantity and speed. The grinding degree of particle depends on the probability of some occurrence taking place after entry and the probability of ore entering zone between the medium shapes (Wills and Napier-munn, 2006). Figure 2.2 below shows the mechanisms of breakage.

Impact or compression – result of force applied normally to surface of particle.

Chipping – due to oblique forces.

Abrasion – due to parallel forces acting on the surface of particle.

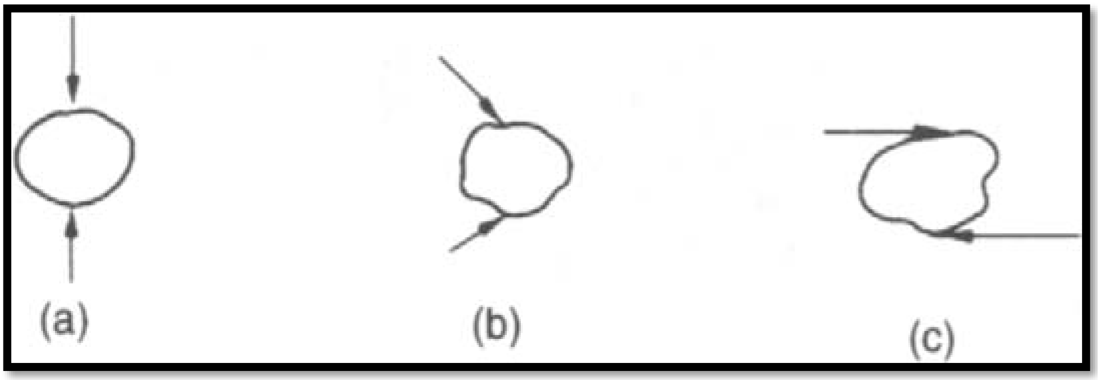

Figure 2.2: Mechanisms of breakage: (a) impact or compression, (b) chipping, (c) abrasion (Wills and Napier-munn, 2006).

2.6 Differences Between Granite and Iron Ore Grindability

(Akande, Adebayo and Akande, 2013) shows that comminuting iron ore and granite rock, it is important to determine the hardness and the grindability characteristics of both materials so that suitable crushing and grinding equipment of suitable power rating can be selected for the comminution process. The choice of appropriate comminution equipment is very important because it is an energy intensive operation. In fact, it has been estimated that fifty percent (50%) of the energy used in processing of materials are consumed at this stage. The most widely used parameter to measure ore grindability is the Bond work index (Wi). This measures the resistance of materials to breakage. From Table 2.1 and Table 2.2, the product produced by grinding process of granite and iron ore are different from each other. This can be seen at the computed PSD for the data obtained by (Akande et al., 2013), and the PSD graph are compared to this research's grinding product that is limestone and granite.

Table 2.1: Results of grinding granite in ball mill (Akande, Adebayo and Akande, 2013)

Sieve size range (μm)	Wt Retained (g)	% Wt Retained	Nominal Aperture Size (μm)	Cumm % Wt Passing	Cumm % Wt Retained
+4750	150.3	30.19	4750	99.99	30.19
-4750 +2000	183.1	36.78	4750	68.80	66.97
-2000 +1700	10.2	2.05	2000	33.02	69.02
-1700 +850	49.7	9.98	1700	30.97	79.00
-850 +600	14.81	2.98	850	20.99	81.98
-600 +425	15.48	3.11	600	18.01	85.09
-425 +212	24.6	4.94	425	14.9	90.03
-212 +150	12.89	2.59	212	9.96	92.62
-150	36.71	7.37	150	7.37	99.99
Total	497.79	100.00	-	-	-

Table 2.2: Result of grinding iron ore in ball mill (Akande, Adebayo and Akande, 2013).

Sieve size range (µm)	Wt Retained (g)	% Wt Retained	Nominal Aperture size(µm)	Cumm % Wt Passing	Cumm % Wt Retained
+4750	60.8	12.19	4750	100.00	12.19
-4750 +2000	53.63	10.75	4750	87.81	22.94
-2000 +1700	71.16	14.27	2000	77.06	37.21
-1700 +850	74.42	14.92	1700	62.97	52.13
-850 +600	87.78	17.60	850	47.87	69.73
-600 +425	79.12	15.87	600	30.27	85.60
-425 +212	46.85	9.40	425	14.40	95.00
-212 +150	15.25	3.06	212	5.00	98.06
-150	9.65	1.94	150	1.94	100.00
Total	498.66	100.00	-	-	-

2.7 Ball Mill

Ball mill is a tumbling mill that uses steel ball as grinding medium. It is usually the last stage in comminution. They are suited for fine finishing as it uses balls which have higher surface area per unit weight than rods. Furthermore, ball mill can be performed either in wet or dry conditions which gives different results. Moreover, ball mil uses a steel ball that act as a grinding media inside it. Ball mill will be efficiently grind a sample at 40% of its filling volume. Nowadays, ball mills are often used in industry because of its efficiency in grinding materials.

2.7.1 Operation

The tumbling ball mill is a grinder used to blend and grind material for reduction process, ore dressing, paint, and etc. Ball mill usually operate with 40% of filling ratio. (Wills and Napier-munn, 2006) states that due to the rotation and friction of the mill shell, the grinding medium is lifted along the rising side of the mill until a position of dynamic equilibrium is reach, when the bodies cascade and cataract down the free surface of the other bodies, about a dead zone where little movement occurs, down to the toe of the mil charge (Figure 2.4). Figure 2.4 can be relate to this research as this motion occurs inside an operating tumbling mill. This motion also affected by variable parameter like rotational speed and ball filling ratio.

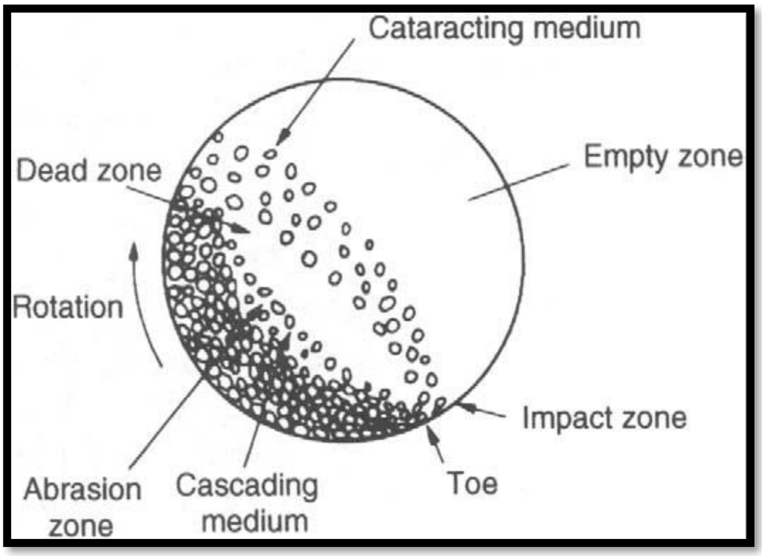

Figure 2.3 : Motion of charge in a tumbling mill (Wills and Napier-munn, 2006)

2.7.2 Breakage Mechanism

Concentrating on breakage behaviour, the mill operation is as follows. The balls and powder are rotated inside the mill as illustrated in Figure 2.3. When the balls fall down, they strike particle nipped against other balls. There are several different mechanisms of fracture which can occur inside the mill. Firstly, a complete break up of a particle (fracture) will occur by a large impact force. Secondly, chipping will occur when a glance blow chip off a corner. Plus, irregular rocks are transformed into roughly spherical pebbles by this mechanism. Thirdly, abrasion will occur when rubbing happen which wear the particle surfaces. Attrition is the combination of abrasion and chipping which leads to the production of fine particles. All of these mechanisms will be at work inside an operating ball mill (Austin, Klimpel and Luckie, 1984). Moreover, reduction of size are mainly by impact although other grinding mechanisms like attrition and shear is also present during milling process (Chauruka *et al.*, 2015).

2.7.3 Effect of Rotational Speed

In ball milling, rotational speed is a very important critical operation conditions that gives great effect in the grinding process. (Austin, Klimpel and Luckie, 1984) stated that the critical speed usually used is between 70% to 85%.(Wang et al, 2012) stated that the best critical speed for grinding is at 80%. Equation 2.1 and 2.2 are the calculation for critical speed.

$$critical\ speed, rpm = \frac{76.6}{\sqrt{(D-d)}} \qquad , (D, d\ in\ ft) \tag{2.1}$$

$$critical\ speed, rpm = \frac{42.2}{\sqrt{(D-d)}} \qquad , (D, d\ in\ m) \tag{2.2}$$

Where:

D = the internal mill diameter

d = the maximum ball diameter

Moreover, there are two types of ball motion that were considered inside an operating ball mill that is, cataracting and cascading. Cataracting motion is a condition where the media are projected clear of the charge to describe a series of parabolas before landing on the toe of the charge. However, cascading motion is a condition where the grinding media tend to roll down to the toe of the charge. (Hong and Kim, 2002) stated that there are 4 motions that occurs inside an operating tumbling ball mill that is, sliding motion, cascading motion, cataracting motion and centrifugal motion. Sliding motion occurs when the jar rolls too slowly making the balls inside the mill roll back down the jar.

Moreover, cascading motion occurs when the speed of the mill is fast enough to lift the ball media to the upper side of the right side of the mill before falling down. Cataracting motion occur when the rotational speed is increases which make the ball lifted to the top site of the right side of the mill and falling back to the bed of material being ground. Finally, centrifugal motion can occur when the speed of mill is too fast which produces large centrifugal force that keeps the ball from falling (Figure 2.4). Abrasive comminution occurs when the tumbling mill have low rotational speed and impact comminution occurs when high rotational speed (cataracting motion) are applied (Wills and Napier-munn, 2006).

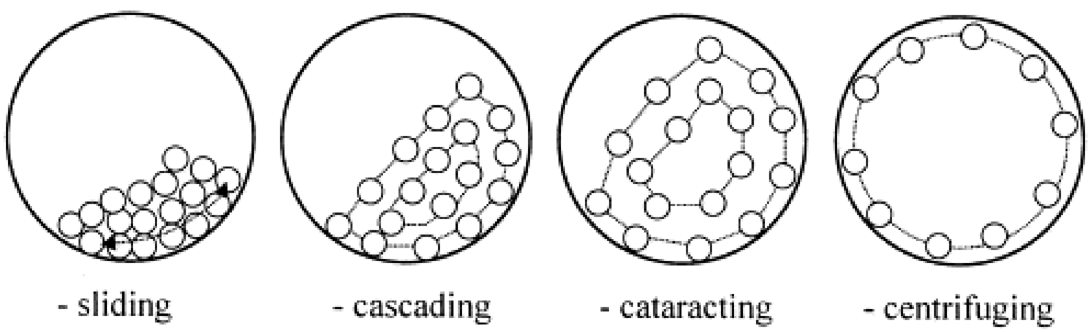

Figure 2.4: Modes of ball motions with rotational speed of jar in tumbling ball mill (Hong and Kim, 2002).

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2.7.4 Effect of Ball Size

Breakage in the ball mill occurs due to direct impact of balls on rock particles and rock particles nipped between balls as they roll or slide over one another (attrition). In the case of impact breakage, the kinetic energy of a grinding ball (and hence its mass) will be directly related to the amount of breakage it will cause for the material.

Considering a representative unit volume of mill, the rate of ball – ball contact per unit time will increase as ball diameter decreases as the number of balls in the mill increases as $1/d^3$. Thus, the rate of breakage of smaller sizes are higher for smaller ball diameters. It appears that the greater impact force of a collision involving a larger ball gives a somewhat bigger proportion of fine fragments (Austin, Klimpel and Luckie, 1984).

2.8 Jet mill

A jet mill is a grinding mill that pulverise fine products by using a high speed inert gas or compressed air to produce particle-particle collision. It is a static machine that consists of a chamber with a nozzle or nozzles (Tuunila and Nyström, 1998). Particles leaving the mill can be separated from the gas stream by cyclonic separation. Moreover, jet mills can be designed to produce ultrafine particles below a certain size, resulting a narrow size distribution of fine particles. There are two common type of jet mills that is fluidized bed jet mill and spiral jet mill.

Jet mills are commonly used to produce particles between 1 µm to 10 µm and are widely used in the chemical, pharmaceutical and mineral industries. Plus, one of the advantage of jet mill is the resulting fine product obtain from the mill is not contaminate because the milling occurs by inter particle collisions**.** However, the disadvantage of using the jet mill is the amount of power needed for the grinding process (Gommeren *et al.*, 2000).

2.8.1 Operation

Spiral mill is one of the type of jet mill used in industry which have the maximum capacity of 25kg/h at 7 bars. First of all, air-pusher will blown the solid feed into the mill chamber. The high pressure air enter the cylindrical chamber through several number of nozzles. Then, the ground particle will have increase in velocity, resulting in the particle-particle collision. Moreover, a centrifugal and drag force will occured inside the jet mill as a rotating stream are created due to the nozzles' direction. Hence, an internal classification will occur where the coarse particle dominate the outer zone whilst the central outlet will be dominate by fine particle. Lastly, the fine particles are collected by a bag filter and the coarse particle are regrind (Gommeren *et al.*, 2000).

Fluidized opposed jet mill used by (Berthiaux, Chiron and Dodds, 1999) describe that the mill is vertical cylindrical-shaped which have the volume of 800 cm^3 and the diameter of 100mm. Firstly, the chamber received the ground particle by the screw feeder. Then, the particle-particle collision occurred by compressed air from three nozzles. It consists of a vertical grinding chamber with opposing gas jets near its lower end. Particles contained in the hopper are continuously fed by screw feeder into the grinding chamber, where they are ground at the meeting point of the three concurrent air jets formed by ceramics nozzles supplied with compressed air. Finally, the fine particle will exit and collected by high efficiency cyclone whilst coarse particle are returned back inside the jet mill (Berthiaux, Chiron and Dodds, 1999).

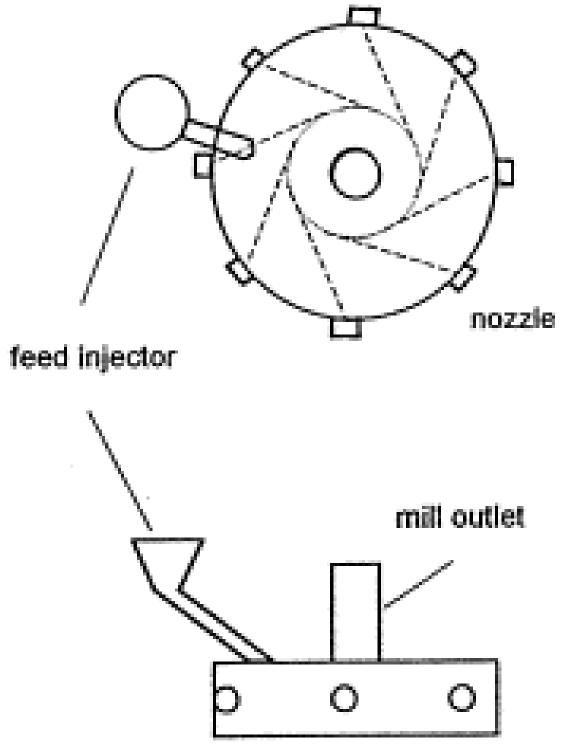

Figure 2.5: Spiral jet mill (Gommeren *et al.*, 2000).

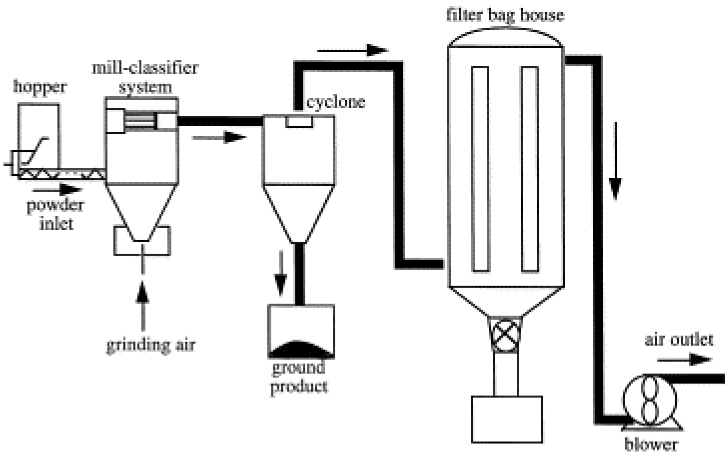

Figure 2.6: Fluidized opposed jet mill (Berthiaux, Chiron and Dodds, 1999)

2.8.2 Breakage Mechanism

There are several operating parameters in the jet mill such as feed rate, classifier rotational speed and grinding (Palaniandy, Azizi Mohd Azizli, *et al.*, 2008). These operating parameters can be change in order study the breakage mechanisms inside the jet mill. Besides that, the operating parameters are greatly affecting the breakage of particles inside the jet mill (Palaniandy, et al., 2008)**.** The main breakage mechanism is destructive breakage due to impact but other breakage mechanisms such as abrasion, primary cleavage and secondary cleavage into blocks also play important roles, dependent on the operating conditions of the grinding mill**.** (Chauruka *et al.*, 2015) also stated that the main stress mode that exist in jet mill is impact, that is particle – particle collision and particle – wall collision.

2.8.3 Effect of Pressure

One of the variables operating parameter inside a jet mill is its pressure. Different pressure will result in different type of mechanism occurred inside it. (Berthiaux, Chiron and Dodds, 1999) stated that, by using lower air pressure, the degree of breakage will likely to be an abrasion mechanism. However, if the pressure was set to be higher, the degree of destructive breakage will be greater.

The main breakage mechanism of particle in a fluidized bed jet mill was impact mechanism, while abrasion also contributed to the particle breakage. Moreover, at low pressure, abrasion mechanism is dominant where the particle speed will be low. Hence, the particles will tend to rub each other in the grinding chamber resulting in the production of debris and trimming of the edges of larger particle. However, large particle with rough surface will be produced if the pressure is high. This is due to the increase of particle acceleration resulting in impact breakage mechanism (Palaniandy, et al., 2008).

These mechanisms produced different sizes and shape of product. It is known that mechanism like abrasion produces finer product than impact breakage. According to (Palaniandy, et al., 2008), the silica produced from different pressure result in different size and shapes.

Firstly, for the impact breakage mechanism, particles produced is at the range of 1 – 10 μm and have sharp edges with irregular shape. Secondly, for abrasion mechanism, particles produce is at range of 0.1 – 1 μm and have smooth and angular shape. Figure 2.7 shows the breakage mechanism of silica inside jet mill.

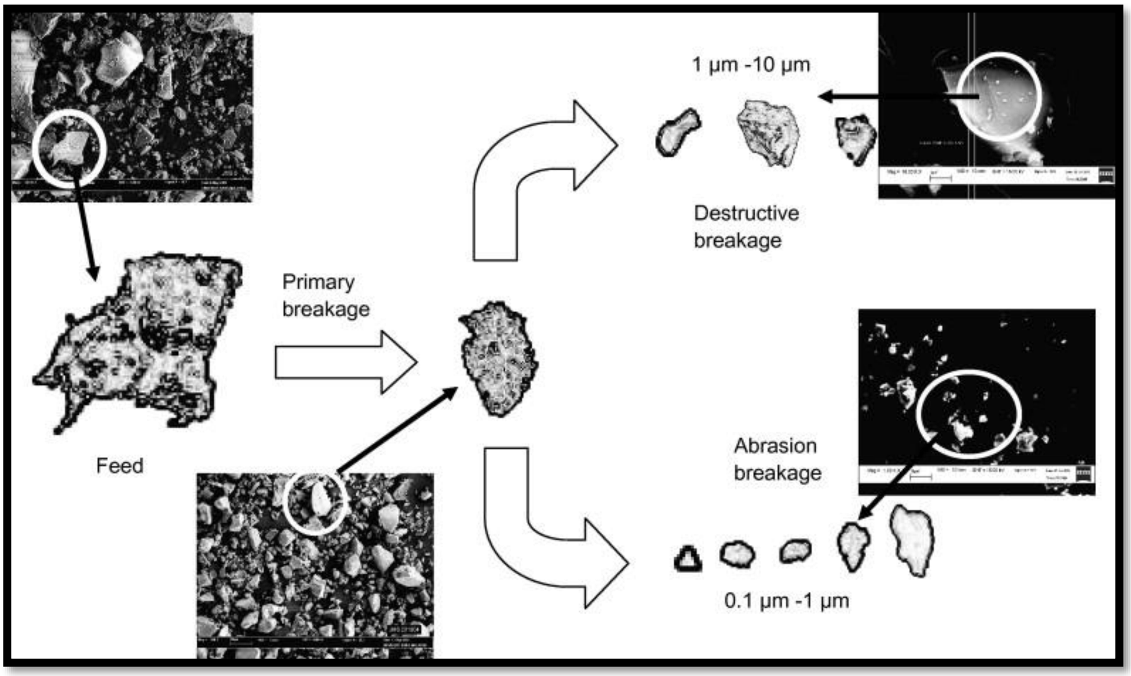

Figure 2.7: Breakage mechanisms of silica in jet mill (Palaniandy, et al., 2008)

2.9 Planetary Mill

Planetary ball mills highlight alluring properties, like the ability to perform under dry or wet condition, easy to operate and clean, and moderate cost**.** Planetary mills are also used to mix and homogenize paste and emulsion for mechanical alloying and activation in material research**.** Moreover, planetary ball mill is suited for fine or ultra-fine grinding process because of its high energy density capability. Furthermore, it is also good for grinding brittle and hard material down to very fine size range (Rosenkranz, Breitung-Faes and Kwade, 2011). It is very popular for laboratory scale process like pharmaceutical industries.

2.9.1 Operation

The planetary mill owes its name to the planet-like movement of its vials as shown in Figure 2.8. Since the vials and the supporting disc rotate in different directions, the centrifugal forces alternatively act in like and opposite directions. This causes the grinding media to run down the inside wall of the vial – the friction effect, followed by the material being milled and milling balls lifting by and travelling freely through the inner chamber of the vial and colliding against the opposite inside wall.

Planetary mills are characterized by very high energy intensities, and as almost the entire energy input is converted to heat temperature of the grinding bowl.

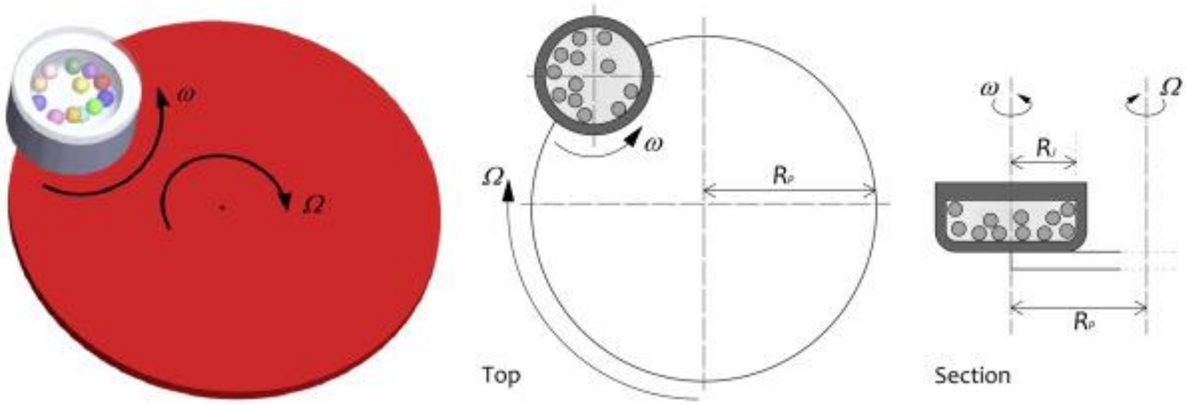

Figure 2.8: Schematic representation of a planetary ball-mill. Left, three-dimensional view; middle and right, definition of the jar radius (Rj) and the distance between axis of rotation (angular velocity) and revolution (angular velocity) Rp.(Broseghini *et al.*, 2016)

2.9.2 Breakage Mechanism

Planetary mill operates in centrifugal forces, which leads to more gentle size reduction process with less abrasion. The extremely high centrifugal forces of the mill results in a very high pulverisation energy and therefore short grinding times. Cascading, cataracting and centrifugal motion also occurs inside a planetary mill (Rogachev *et al.*, 2015). It is suitable for ultra-fine grinding process as it is a high energy mill, where shearing and compression are more dominant than high velocity collisions (Chauruka *et al.*, 2015).