PRINCIPLES OF CRUSHING, GRINDING AND GRINDABILITY

1.0 Introduction:

Mineral processing can involve four general types of unit operations. They are: 1) comminution – the process of particle size reduction; 2) sizing – separation of particle sizes by screening or classification; 3) concentration by taking advantage of physical and surface chemical properties; and 4) dewatering – solid/liquid separation.

Size Reduction is mainly done through crushers and mills. Crushing and grinding are the two primary comminution processes. Crushing is normally carried out on the "run-of-mine" ore. The grinding process which is normally carried out after crushing, may be conducted on dry or slurried material.

2.0 The size reduction process:

Minerals being crystals have a tendency to break into endless numbers of sizes and shapes every time they are introduced to energy. The difficulty in size reduction lays in the art of limiting the number of over and under sizes produced during the reduction. If this is not controlled, the mineral will follow its natural crystal behaviour, normally ending up in over-representation of fines.

3.0 Comminution

Comminution is particle size reduction of materials. Comminution may be carried out on either dry materials or slurries. Crushing and grinding are the two primary comminution processes. Crushing is normally carried out on "run-of-mine" ore, while grinding (normally carried out after crushing) may be conducted on dry or slurried material. In comminution, the size reduction of particles is done by three types of forces: compression, impact and attrition.

4.0 Crushing of rock and minerals:

Crushing is the largest process operation in minerals processing. The goal is to produce rock or (more seldom) mineral fractions to be used as rock fill or ballast material for concrete and asphalt production. Quality parameters are normally strength, size and shape. The kinds of materials processed are Limestone, Granite, Gabbro, Basalt, River Stone, Coal Gangue, Quartz, Diabase, Iron Ore, Copper Ore, Zinc Ore and Manganese Ore.

4.1 The art of crushing:

Crushing means different things for different operations and the production goals are not always equal. In Mineral dressing, these two approaches are adopted: 1. Crushing of rock and gravel 2. Crushing of ore and minerals. There are three stages in crushing as stage 1, 2 and 3. In each stage the reduction in size ranges as referred to as R1,R2 and R3. This diagram illustrates the stages with equipments and reduction ratios. From 1000mm to 100 micron levels the mass is crushed.

4.2 Size control:

Neither crushers nor grinding mills are very precise when it comes to the correct sizing of the end products. The reason is to find partly in the variation of the mineral crystals compounds (hard-soft, abrasive – non abrasive), partly in the design and performance of the equipment. Size control is the tool for improvement of the size fractions in the process stages and in the final products. For the coarser part of the process, screens are used (in practise above 1-2 mm). In the finer part we have to use classification with spiral classifiers.

Jaw crusher:

A jaw crusher uses compressive force for breaking of particle. This mechanical pressure is achieved by the two jaws of the crusher of which one is fixed while the other reciprocates. A jaw or toggle crusher consists of a set of vertical jaws, one jaw is kept stationary and is called a fixed jaw while the other jaw called a swing jaw, moves back and forth relative to it, by a cam or pitman mechanism, acting like a class II lever or a nutcracker. The volume or cavity between the two jaws is called the crushing chamber. The movement of the swing jaw can be quite small, since complete crushing is not performed in one stroke. The inertia required to crush the material is provided by a flywheel that moves a shaft creating an eccentric motion that causes the closing of the gap.

Gyratory crusher

A gyratory crusher is one of the main types of primary crushers in a mine or ore processing plant. Gyratory crushers are designated in size either by the gape and mantle diameter or by the size of the receiving opening. Gyratory crushers can be used for primary or secondary crushing. The crushing action is caused by the closing of the gap between the mantle line (movable) mounted on the central vertical spindle and the concave liners (fixed) mounted on the main frame of the crusher. The gap is opened and closed by an eccentric on the bottom of the spindle that causes the central vertical spindle to gyrate.

Cone crusher

A cone crusher is similar in operation to a gyratory crusher, with less steepness in the crushing chamber and more of a parallel zone between crushing zones. A cone crusher breaks rock by squeezing the rock between an eccentrically gyrating spindle, which is covered by a wear-resistant mantle, and the enclosing concave hopper, covered by a manganese concave or a bowl liner. As rock enters the top of the cone crusher, it becomes wedged and squeezed between the mantle and the bowl liner or concave. Large pieces of ore are broken once, and then fall to a lower position (because they are now smaller) where they are broken again. This process continues until the pieces are small enough to fall through the narrow opening at the bottom of the crusher.

Impact crusher

Impact crushers involve the use of impact rather than pressure to crush material. The material is contained within a cage, with openings on the bottom, end, or side of the desired size to allow pulverized material to escape. There are two types of impact crushers: horizontal shaft impactor and vertical shaft impactor.

Mineral sizers:

Mineral sizers are a variety of roll crushers which use two rotors with large teeth, on small diameter shafts, driven at a low speed by a direct high torque drive system. This design produces three major principles which all interact when breaking materials using sizer technology. The unique principles are the three-stage breaking action, the rotating screen effect, and the deep scroll tooth pattern.

Principle Of Grinding:

Grinding Machines:

Grinding Machines are also regarded as machine tools. A distinguishing feature of grinding machines is the rotating abrasive tool. Grinding machine is employed to obtain high accuracy along with very high class of surface finish on the workpiece. However, advent of new generation of grinding wheels and grinding machines, characterised by their rigidity, power and speed enables one to go for high efficiency deep grinding (often called as abrasive milling) of not only hardened material but also ductile materials.

Conventional grinding machines can be broadly classified as:

(a) Surface grinding machine
(b) Cylindrical grinding machine
(c) Internal grinding machine
(d) Tool and cutter grinding machine

2.1 Surface grinding machine:

This machine may be similar to a milling machine used mainly to grind flat surface. However, some types of surface grinders are also capable of producing contour surface with formed grinding wheel. Basically there are four different types of surface grinding machines characterised by the movement of their tables and the orientation of grinding wheel spindles as
follows:

- Horizontal spindle and reciprocating table
- Vertical spindle and reciprocating table
- Horizontal spindle and rotary table
- Vertical spindle and rotary table

2.2 Cylindrical grinding machine

This machine is used to produce external cylindrical surface. The surfaces may be straight, tapered, steps or profiled. Broadly there are three different types of cylindrical grinding machine as follows:

1. Plain centre type cylindrical grinder
2. Universal cylindrical surface grinder
3. Centreless cylindrical surface grinder

2.3 Internal grinding machine

This machine is used to produce internal cylindrical surface. The surface may be straight, tapered, grooved or profiled.

Broadly there are three different types of internal grinding machine as follows:

1. Chucking type internal grinder
2. Planetary internal grinder
3. Centreless internal grinder

2.4 Tool and cutter grinder machine:

Tool grinding may be divided into two subgroups: tool manufacturing and tool resharpening. There are many types of tool and cutter grinding machine to meet these requirements. Simple single point tools are occasionally sharpened by hand on bench or pedestal grinder. However, tools and cutters with complex geometry like milling cutter, drills, reamers and hobs require sophisticated grinding machine commonly known as universal tool and cutter grinder. Present trend is to use tool and cutter grinder equipped with CNC to grind tool angles, concentricity, cutting edges and dimensional size with high precision.

Principle of Grindability

Ore grindability refers to the ease with which materials can be comminuted, and data from grindability tests are used to evaluate crushing and grinding efficiency. Probably the most widely used parameter to measure ore grindability is the Bond work index Wi.

If the breakage characteristics of a material remain constant over all size ranges, then the calculated work index would be expected to remain constant since it expresses the resistance of material to breakage. However, for most naturally occurring raw materials, differences exist in the breakage characteristics depending on particle size, which can result in variations in the work index. For instance, when a mineral breaks easily at the boundaries but individual grains are tough, then grindability increases with fineness of grind. Consequently work index values are generally obtained for some specified grind size which typifies the comminution operation being evaluated (Magdalinovic, 1989). Grindability is based upon performance in a carefully defined piece of equipment according to a strict procedure. The Bond standard grindability test has been described in detail by Deister (1987), and Levin (1989) has proposed a method for deter- mining the grindability of fine materials. Table 5.1 lists standard Bond work indices for a selection of materials.

Table: **Selection of Bond work indices**

Material	Work index
Barite	4.73
Bauxite	8.78
Coal	13.00
Dolomite	11.27
Emery	56.70
Ferro-silico	10.01
Fluorspar	8.91
Granite	15.13
Graphite	43.56
Limestone	12.74
Quartzite	9.58

The standard Bond test is time-consuming, and a Number of methods have been used to obtain the indices related to the Bond work Indec. Smith and lee(1968) used batch-type grindability tests to arrive at the work index, and compared their results with work indices from the standard Bond tests, which require constant screening out of undersize material in order to simulate closed-circuit operation. The batch-type tests compared very favourably with the standard grindability test ata, the advantage being that less time is required to determine the work index. Berry and Bruce (1966) developed a comparative method of determining the grindability of an ore. The method requires the use of a reference ore of known grindability. The reference ore is ground for a certain time and the power consumption recorded. An identical weight of the test ore is then ground for a length of time such that the power consumed is identical with that of the reference ore. If r is the reference ore and t the ore under test, then from Bond's Equation 5.2.

$$W_r = W_t = W_{ir}\left[\frac{10}{\sqrt{P_r}} - \frac{10}{\sqrt{F_r}}\right] = W_{it}\left[\frac{10}{\sqrt{P_t}} - \frac{10}{\sqrt{F_t}}\right]$$

Therefore

$$W_{it} = W_{ir}\left[\frac{10}{\sqrt{P_r}} - \frac{10}{\sqrt{F_r}}\right] \Big/ \left[\frac{10}{\sqrt{P_t}} - \frac{10}{\sqrt{F_t}}\right]$$

Reasonable values for the work indices are obtained by this method as long as the reference and test ores are ground to about the same product size distribution. The low efficiency of grinding equipment in terms of the energy actually used to break the ore particles is a common feature of all types of mill, but there are substantial differences between various designs. Some machines are constructed in such a way that much energy is adsorbed in the component parts and is not available for breaking. Work indices have been obtained (Lowrison, 1974) from grindability tests on different sizes of several types of equipment, using identical feed materials. The values of work indices obtained are indications of the efficiencies of the machines. Thus, the equipment having the highest indices, and hence the largest energy consumers, are found to be jaw and gyratory crushers and tumbling mills; intermediate consumers are impact crushers and vibration mills, and roll crushers are the smallest consumers. The smallest consumers of energy are those machines which apply a steady, continuous, compressive stress on the material. Values of operating work indices, **Wio**, obtained from specific units can be used to assess the effect of operating variables, such as mill speeds, size of grinding media, type of liner, etc. The higher the value of **Wi**, the lower is the grinding efficiency. The **Wio** can be obtained using Equation , by defining W as the specific energy being used (power draw/new feed rate), F and P as the actual feed and product 80% passing sizes, and **Wi** as the operating work index, **Wio**. Once corrected for the particular application and equipment-related factors, **Wio** can be compared on the same basis as grindability test results.

This allows a direct comparison of grinding efficiency. Ideally **Wi** should be equal to **Wio** and grinding efficiency should be unity. It should be noted that the value of **W** is the power applied to the pinion shaft of the mill. Motor input power thus has to be converted to power at the mill pinion shaft unless the motor is coupled direct to the pinion shaft. While Bond is the best-known grindability test for rod and ball mills, in recent years the SPI (SAG Power Index) test has become popular for SAG mills. The SPI test is a batch test, conducted in a 30.5 cm diameter by 10.2 cm long grinding mill charged with 5 kg of steel balls. Two kilograms of sample are crushed to 100% minus 1.9 cm and 80% minus 1.3 cm and placed in the mill. The test is run with several screening iterations until the sample is reduced to 80% minus 1.7 mm. The time required to reach a P80 of 1.7 mm is then converted to an SAG power index **Wsag** via the use of a proprietary transformation (Starkey and Dobby, 1996):

$$W_{sag} = K f_{sag} \left(\frac{SPI}{T_{80}^{0.5}} \right)^n$$

The parameters **K** and **n** are empirical factors whilst **f**sag incorporates a series of calculations (unpublished), which estimate the influence of factors such as pebble crusher recycle load, ball load, and feed size distribution. The test is essentially an indicator of an ore's breakage response to SAG abrasion events. As with other batch tests, the test is limited by the fact that a steady state mill load is never reached.