MECHANICAL OPERATIONS LAB REPORT

Experiment 3: Ball Mill

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AIM

- Understand and capture the essence of Ball size on the Particle size reduction
- Study the influence of Mill rotation speed on Grinding, Derive critical speed.

APPARATUS

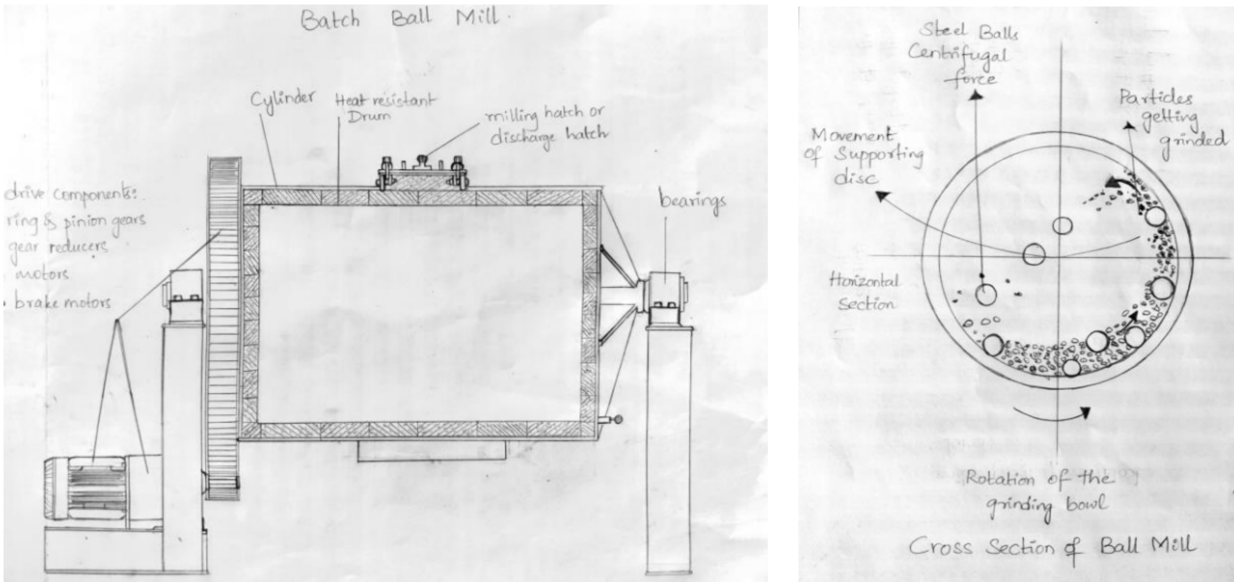
1) Batch Ball Mill 2) Different sizes sets of steel balls – total mass of each set remains the same 3) Sieve Shaker Machine 4) British Standard Sieve – 30 sizes mesh 5) Feed Particles for grinding - Limestone 6) Collecting Bin 7) Weighing Machine 8) Stopwatch

THEORY

A ball mill is a type of grinder used to grind or blend materials for use in mineral dressing processes, paints, pyrotechnics, ceramics. Ball mill is a closed cylindrical setup in which the inner surface area of the cylinder is painted with heat resistant paint. The feed material and the balls are fed into the cylinder and the cylinder is rotated with the help of the motor. The reduction in the size of the particles takes place due to attrition and impact forces under a given rpm of the cylinder which is necessary to prevent centrifugation.

Ball Mill Machine used in the experiment is Batch Ball Mill because we place the feed inside and remove it only after the completion of the process, and there's no rate of feeding of our mixture. In industries, there will be continuous Ball Mills where the input and output are present at the axial ends of the Drum. Mill Drum is made up of a heat resistant material. Influence of Angular Speed of the Rotating Mill on the efficiency of grinding: If the rotating speed is low, the balls oscillate on the inner walls of the mill, due to continuous dragging over the inner surface, the mixture experiences shear forces (attrition) by the balls which will be responsible for grinding. If the rotating speed is high, the balls experience enough centrifugal forces to revolute only on the inner surface of the mill along with its speed. In this case, there will be slight attrition; and the corresponding angular speed is called critical speed. Between these two extreme speeds, there will be a point where Balls move along the inner surface and fall with a projectile motion due to the lack of enough centrifugal force from a certain point. Hence, the mixture will be experiencing both Impact & Shear forces from the Balls, making it an optimum point for operation. The Operating speed is generally considered as 60-70% of Critical Speed.

EXPERIMENTAL SET-UP



Hand drawn schematic of the Ball Mill

Observations

Feed Specifications		
Size	**Mass (gm)**	**Milling Time**
+0.25", -0.5"	200 g	5 min

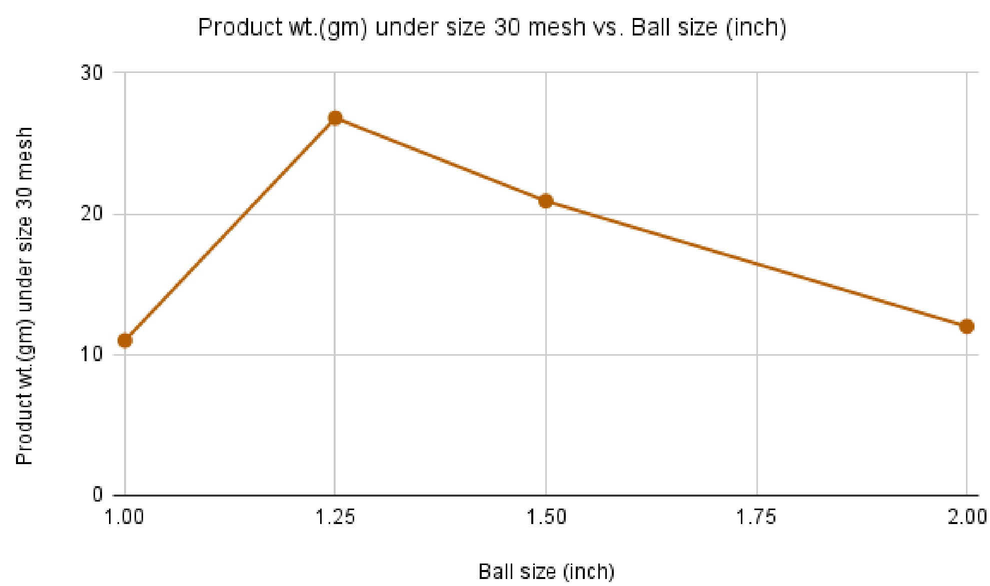
$$\text{Average Feed size} = \frac{0.25'' + 0.5''}{2}$$

$$= 0.875''$$

$$\therefore \text{Average Feed size} = 9.525 \text{ mm}$$

Ball size (inch)	No. of Balls	Product wt.(gm) under size 30 mesh
1	23	11
1.25	10	26.8
1.5	7	20.9
2	3	12

GRAPH



- The scatter plot should be limited only to the given data points without joining them, as our data set is discrete.
- However, if we want to find a trend so as to make a rough estimate for the ball sizes in between (interpolation) the range or to forecast (extrapolation), we can do a polynomial fit as shown below.
- The occurrence of local minima can be rectified if we have more data points in the ball size range of [1.5inch, 2inch]

RESULTS AND CALCULATIONS

Larger Balls impose more impulsive forces due to the individual large masses. Smaller Balls impose more shear forces due to the large surface area by collective more balls. Hence, there will be a ball size not too large, not too small, where we get optimum efficiency for the desired output. It is for this comparison, we consider different ball sets with the same total mass.
From the scatter plot, we found out that Ball Size = 1.25inch = 0.03175m, gives the maximum desired product i.e., particles undersize to 0.5mm.
From the force balance, the critical speed of the Ball mill is given to be,

$$g = \frac{v_c^2}{(R-r)} = \frac{4\pi^2 (R-r)^2 \omega_c^2}{(R-r)\times 3600} \quad \text{, where } v = 2\pi(R-r)\omega/60 \text{ rpm}$$

$$\Rightarrow \omega_c = \frac{42.3}{\sqrt{(D-d)}} \quad rpm$$

$$\therefore Operating\ \omega_c = 0.7 \times \frac{42.3}{\sqrt{D - 0.03175}} rpm, where\ D = Mill\ inner\ Diameter$$

DISCUSSION

- Error Analysis: One of the possible chances for the diversion of Efficiency is while collecting the product. As our desired product is undersize of 50 microns, the careful collection of finer particles plays an important role. But as our machine works under Batch Operation, lot of finer particles be lost as dust while removing Balls and Mixture after the grinding process – Some get stuck to the hands and some falls of easily. As our output is fixed, we need to use the respective particular Mesh size of Sieve instead of a stage-wise assembly, because we might lose some finer particles on the top layers as they stay with larger particles. For an efficient operation i.e., to force the occurrence of Impact and Attrition by the balls, many lifters are placed along the inner surface of the drum which obstructs the happening of complete centrifugal action. The cylinder should be rotated under the critical rotation speed so as to avoid centrifugation as it results in bad grinding. Material of the grinding ball should be hard enough, porous material or the material same as that of the feed particles can not be used to make the ball for grinding as they will themselves get grinded or the grinding will be very poor. When the balls are large in size, impact force dominates and when the balls are smaller in size attrition force dominates, grinding will be better when there is a balance of the above two forces, that is why maximum grinding comes for 1.28 inches ball which is nearly in between of the given size. More time given for milling and sieving better will be the amount of desired output

- If we maintain the same total mass as used in the experiment and increase the density, impulsive force won't change because of no change in the mass. Also, shear forces reduce because of a reduction in the surface area. However, if we use Larger density material by keeping the volume of the ball constant, the impact force increases because of the increase in mass. We need to choose such a material that will not have an effect on its structure by breaking because of the forces inside the rotating mill. So, choosing the balls with a density close to that of feed will be too soft for the operation which might break.

- Small ball sizes have large shear forces not only on each particle but as a collective mixture because of their less void fraction when put together. This enables the balls to have a large contact surface sharing with the mixture. Ball Mill is used as a secondary crusher (grinding), so the feed size we need to provide as input should already undergo a primary crushing from Jaw Crusher, Roll Crusher, etc. Hence, a larger Feed size will lead to an inefficient Grinding process. Also, the lower limit for feed size is governed by the void fraction of Steel balls we use for the operation.

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