

The design of ball mill, intended for grinding dolomite rocks

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Abstract

The design of ball mill, intended for grinding dolomite rocks. During the process of designing, construction assumptions like the dimensions of final products were strictly considered. The process of milling requires setting in motion the barrel of ball mill. Corrugating plates lift crumbling elements on the proper height. Then, these elements crumble the material inside by falling down and hitting it. Fragmentation process is about splitting material grains into smaller. Projected ball mill is composed of three compartments of different lengths and fulfillment. This type of construction is widely used in industry. Particular compartment has miscellaneous kind of crumbling balls. They differ by dimensions, volume or shape – it has to be properly adjusted for great level of crumbling. It is necessary to remember about proper materials of crumbling elements and corrugating plates because they are highly exposed on the powers of abrasion.

Keywords: ball mill; crumbling; fulfillment; materials; calculations

1. Theory of fragmentation process

Fragmentation is a physical process of dividing block solids into smaller particles. The phenomenon occurs as a result of the influence of external forces. Cutting the material also includes single grains. The result of the discussed process is the reduction of the linear dimensions of the grains, which leads to the enlargement of their surface in relation to the initial structure. Gradation of the particle surface speeds up the course of chemical or physical changes in which the solid phases take part.

In the industry, both raw material and its products are subject to milling processes. The grain size is determined by granulation. Depending on the purpose, they are subject to the appropriate standards. The entire grinding process is reduced to obtaining particles with an appropriate granulation value. The particle dimensions determine their usefulness and application.

There are seven main ways to carry out the fragmentation process. The differences between them depend on the principle of the impact of the apparatus on the material to be crushed, and the type and size of forces used in the process. [1],[2]

a) Crushing

The process takes place in specially designed for this equipment, crushers. The crusher has two plates: fixed and movable, which under the influence of successive force increase, crushes the material inside. Exceeding the critical value by the amount of compressive force results in cracking of the grain, which disintegrates into smaller particles. [1]

b) Splitting

The implementation of this method is possible by using two plates with projections of various geometrical shapes - however, the most commonly practiced solutions are equilateral triangles. The material is fragmented

using a compressive force with opposite turns, acting on the grains located between the splines. The crack line starts running along the ridges of the splines. If the force limit value is exceeded, the material breaks out. [1]

c) Tearing

The method consists in subjecting grains to forces with opposite lines of return. Exceeding the permissible force value causes the material to be divided. [1]

d) Striking

The material is crushed under the influence of intense impact of crush forces. The process is sudden and proceeds at a fast pace. [1]

e) Bending

Grain is placed between two special plates that cause bending moments. Plate geometry is varied, but it must meet the condition regarding the moments under which the material is fragmented. [1]

f) Abrasion

The frictional force created between the grain and the plates moving in opposite directions is the driving force of the grinding process in this method. [1]

g) Shearing

Working on the grain with two forces of opposite turns, causes the surface cross-sections to move relative to each other, which results in material crumbling. [1]

The presented methods are used in industrial production, in all kinds of crushing apparatus. A practical solution that has been used many times is to coupling two operations together, in order to obtain a greater degree of fragmentation.

Criteria for selecting the right grinding technique and apparatus enabling this process to be carried out are

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closely related to the physical properties of the grain. The main material parameters that are taken into account in this selection are: [1], [2]

- Dimension of solid particles,
- Structure,
- Strength (bending, impact),
- Fragility,
- Hardness,
- Elasticity.

The amount of moisture stored in the solid body is also important, because too much percentage of moisture in the particle eliminates even the grinding process by abrasion.

The structure of the material to be crushed can be porous or compact, and the structure: crystalline, amorphous or fibrous. The latter usually occurs in the porous structure - then the methods of abrasion or tearing are well suited, and splitting or crushing is not applicable here. Grains with porous structure and fibrous structure impose the most restrictions on the selection of the grinding method, while for other forms and structures each technique plays a role.

The hardness of the grain is associated with its strength. There was some correlation between these features - as the hardness of the material increases, its impact strength decreases, due to the high speed of branching of the deformations. In turn, when the grain is characterized by greater softness, its crush strength decreases. Abrasion is a desirable method of grinding in this case. The grain hardness defined as the resistance to surface damage is determined by the resistance made during the test of indentation to the material, the indenter of the appropriate shape, characteristic for particular hardness measurement methods. To estimate the degree of hardness, the scale developed by Mohs, Rossival and also by practical determination is used.

Another parameter that has a big impact on the selection of the right device, and the adoption of the method is the particle size of the material supplied. [1], [2]

Table 1. The sizes of the feed grains.[1]

Particle size	Fragmentation
> 50 [mm]	Thick
5 – 50 [mm]	Medium
0,5 – 5 [mm]	Minor
50 – 500 [μm]	Distinctly minor
5 – 50 [μm]	Ultraminor
< 5 [μm]	Colloidal

The grinding process by abrasion is the right solution for minor and smaller particles. Splitting or hitting is used for medium sizes, while coarse grains are subjected to crushing or bending. [1]

2. Construction of ball mill

The purpose of ball mills is to grind supplied material into granules, which linear dimensions cannot exceed 5 [mm]. Ball mill is one of the most conventional device applied to conduct a process of milling. This process is working by crumbling and attrition. Crumbling is possible with the use of mulching elements perched inside the barrel. Attrition comes around through the relative move of fulfillment.

Producer takes into consideration and selects the best solutions during the process of designing, for example: the dimensions of ball mill (the length and the diameter), the frequency of rotation, the way of filling up and clearing out the mill or the kind of crumbling materials.

The mill should be designed in the way of including the planned value of mass efficiency. Regarding to that quantity the burden of mill must be possibly the least. [2], [3]

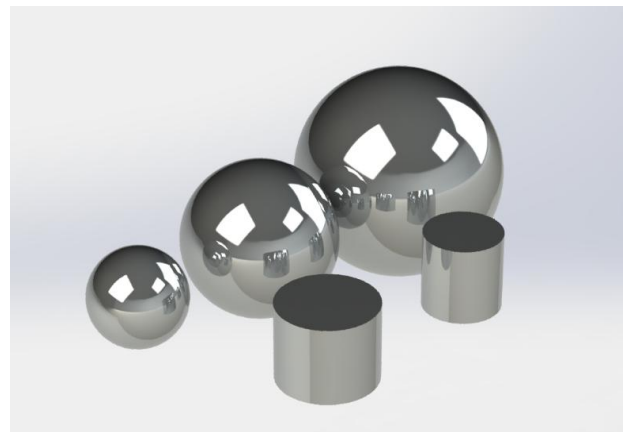
2.1. Crumbling elements

The fragmentation process depends on the type and the size of fulfillment. To estimate the correct amount of crumbling balls, the level of filling of barrel has to be known. Level of filling defines the volume taken by crumbling components. These elements can be:

- Rollers - rolls of small dimensions, they are in the last chamber (their task is to rub the material just before leaving the mill).
- Balls - crush the material transmitted by falling from the appropriate height .The largest balls (diameter Ø90 [mm]) are placed in the first chamber, while in the second compartment grinding media are of a relatively smaller size (diameters are within the range of Ø30-60 [mm]).

Crumbling elements are made of manganese steel, which abrasion-resistant material. Balls and rollers can also be made of steel, chrome-plated steel, stainless steel or ceramic. [2],[3]

Picture 1. Crumbling elements.



2.2. The dimensions of compartments

Many solutions have been developed to adopt the optimal chamber lengths, ensuring the best performance of the mill. The selection of appropriate dimensions is conditioned by the type and size of the feed, the purpose of the mill and the expected degree of product fragmentation.

The general rule is to divide the mill according to Labahn's theory: [2], [4]

- The first chamber – 20% of the total length of the drum,
- The second chamber – 30% of the total length of the drum,
- The third chamber – 50% the total length of the drum.

As was mentioned before, the dimensions of a mill are determined by many factors. For mills with three chambers where grains of a small-sized product are obtained, the last, third chamber is often extended. In mills intended for the production of cement, the size of the chambers are within the following thresholds: [2], [4]

- The first chamber – 25 to 32% of the total length of the drum,
- The second chamber – 18 to 21% of the total length of the drum,
- The third chamber – 50 to 55% of the total length of the drum.

The most cost-effective dimensions are selected experimentally, analyzing the operation of the device. [2]

2.3. Corrugating plates

The equipment of the mill in the corrugating lining has a great impact on the efficiency of the work, due to the fact that the transmission power from the engine is transferred to the grinding elements. The role of corrugating plates is not only limited to power transmission, but also to protect the wall of barrel against grinding media falling on it.

The process of fragmentation in the first chamber is preliminary, the largest grinding elements are intended for this process. The corrugating liner should have the ability to lift the ball to the correct height, the operation must be even - for this to happen, the entire surface of the plate should be involved in ball raising, because in this case a high coefficient of friction between the grinding elements and the plates is achieved. Plates should also have the appropriate geometry. Otherwise, the lack of "humps" may cause damage to the boards, due to the falling of grinding media from too high a height. The diameter of the mill should be taken into consideration when selecting the appropriate type of plates, because with larger diameters, there is a high probability of sliding crumbling elements. The phenomenon causes excessive vibrations, affecting the harmonious operation of the device. Corrugating plates can be mounted to the wall by

expanding wedges, articulated locks, but bolts are commonly used. The screws, however, weaken the liner, which becomes more susceptible to impact. [2], [3]

Picture 2. Corrugating plates.



3. Calculations

The designed apparatus is a type of tubular three-chamber mill. It will crush the dolomite rock. The size of the feed particles is $D = 25 [mm]$, and the particles of the ground product $d = 0,2 [mm]$. The required property of the material fed - dolomite, is its bulk density, equal $\rho_{feed} = 2,8 \left[\frac{t}{m^3} \right]$. Next relevant parameter is the appropriate mass efficiency of the mill, which will be: $Q_m = 20 \left[\frac{t}{h} \right]$. According to these construction assumptions the values appear as follows.

- The diameter of the barrel: $D_b = 2 [m]$
- The length of the barrel: $L_b = 9,45 [m]$
- The frequency of rotation: $n = 0,378 \left[\frac{1}{s} \right]$
- Material of crumbling elements: manganese steel L45G,
- Dimensions of particle compartment: $L_I = 2,74 [m]$, $L_{II} = 1,98 [m]$, $L_{III} = 4,73 [m]$,
- Mass of crumbling elements: $m_{mtn} = 61335,5 [kg]$,
- Mass of grinded material: $m_{mat} = 11324,88 [kg]$,
- Mass of barrel: $m_b = 8795,077 [kg]$,
- Mass of corrugating plates: $m_{pl} = 13720 [kg]$,
- Mass of mill: $M_{mill} = 95,18 [t]$,
- Calculation of grinding power (effective power): $N_r = 630,36 [kW]$,
- Friction resistance of journals in bearing: $F = 206082,041 [N]$,
- Material of the shaft journal: steel E335,
- Material of the rolls and rims: Hadfield's steel,
- The power needed to overcome the frictional resistance: $N_r = 250,703 [kW]$,

- Electrical power demand for whole process: $N'_r = 655,286 [kW]$,
- Material of gearwheel: steel 20MnCr5,
- Thickness of the drum wall: Maximum bending moment $Mg_{max} = 205635,308 [Nm]$, Thickness of the wall $t_w = 0,019 [m]$,
- Emptying the mill – speed of wind flow: $w = 13 [\frac{m}{s}]$.

4. Concluding information

The ball mill project is based on the use of apparatus in the industrial production of cement. The mill is composed of three chambers, this type of construction is the most commonly practiced in this field of industry. All proposed solutions are based on concepts used on an industrial scale, and have been adapted to obtain the most optimal results.

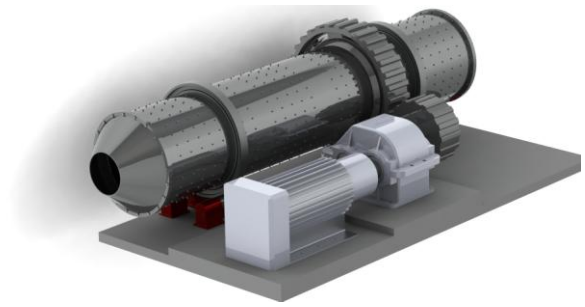
The selection of the right type and size of grinding media is an extremely important issue during designing the device. The grinding degree of the final product depends on the grinding elements. Remember that the crumbling elements should be made of abrasion-resistant steel. The grinding elements and the drum liner are being damaged by the process of milling. Regular inspection, maintenance, or replacement of corrugating plates and crumbling components is a duty for proper operation and proper grinding efficiency.

The rollers on which the drum is based are equipped with appropriate bearings. Their geometry is perfectly matched to the mill's rim. The use of bearings allows to reduce the friction resistance, which also results in less power demand. The spacing of supports also plays an important role. With the dimensions and mass of the device, the load must be evenly distributed so that the safety conditions are not exceeded.

The calculations concerning the electric power demand take into account the filling level of individual mill chambers. Electric power can also be determined by using empirical formulas, but the power needed to overcome the frictional resistance is neglected during calculations. The ball mill gear also requires proper bills, taking into account the moments acting on the rim.

Materials used in the designed mill were selected in terms of operating conditions of a given part. As mentioned earlier - abrasion resistant, manganese cast steel is used for corrugating plates and crumbling elements. The gear wheel is made of alloy steel designed for carburizing, resistant to high surface pressures and variable loads. Hadfield steel, from which rollers and rims are made, is strengthened during the work. The abrasion and pressure occurring between the roller and the rim favors the improvement of this property. Hence, its use in the production of these parts results. Selection of structural steel of ordinary quality, as the material from which the drum is made, is only to meet the strength conditions, because the mill is not exposed to damage resulting from working in a corrosive environment.

Picture 3. Ball mill.



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