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Advanced Computing for Energy Efficiency of Milling Processes.

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Abstract. *In this paper is paid attention to the research of milling processes in different operational modes and simulations of grinding bodies with different shapes (spheres and spherical tetrahedrons). The simulation is made with software, which is working on the discrete elements method - EDEM Software. The influence of the shape of milling bodies on the energy efficiency of milling processes is investigated. Analysis of the results are made. The results of experiments for milling of ore and cement in different regimes and with different grinding bodies are presented.. The critical speed of the ball mill is also defined. Mills in most cases operate at 65% to 85% of the critical speed. This study uses 75% of the critical one, which is 57 rpm. It reaches the most used mode – the cataract one.With the help of the EDEM Software we define and simulate the impact force, the angle of separation of the shoulder and the angle of incidence (falling) in cases of different working regimes and different shape and size of the milling bodies. The total force of a selected particle is calculated.For the energy efficiency of milling processes are important both - the quality of the milling (speed, size and consumption) as well as the energy consumption for preparing the materials (the heating and temperature distribution).*

Keywords: *milling processes, RELOE tetrahedron, ball mills*

1 Introduction

Minerals with sufficient content of useful minerals are fuel, ore and gangue. They are processed in order to increase the rate of the useful substance and to be obtained so called initial material. The effectively carrying out of the enrichment process requires an initial product to undergo the technological processing for averaging the mineral and chemical composition of the product. [1, 3, 15]

Crushing. Crushing is a necessary process to reduce the ore pieces by applying external forces that cause mechanical crushes of the ore. Most ores consist of solid and sturdy rocks which need to be broken, facilitating the extraction of minerals. Fragmentation is performed in stages. In the initial stage (up to 150 mm) are used devices named jaw crushers. The next stage is secondary crushing performed in the cone crushers. The ore is crushed to 15mm in diameter and enters in the mill. [1, 14, 16, 17].

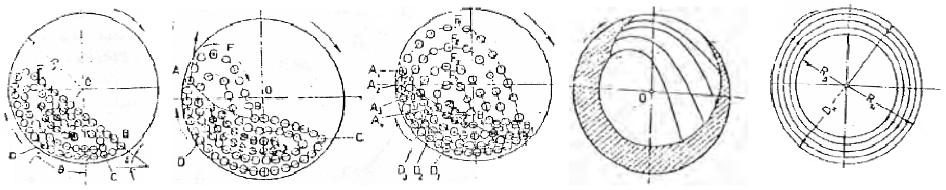
2 Classification and operational principle of milling machines.

Milling is the last stage of the crushing of the starting material, depending on the particle size of the finished product. It can be roughly (1,5 – 0,3 mm), fine (0,1 – 0,07 mm) and ultrafine (0,01 – 0,005 mm). The destruction of the material is usually applied by impact, grinding and partly by crushing. Depending on the principle of operation and construction mills can be defined as: drum (destroy material by impact and grinding), inertial roller mills, impact mills and jet mills. [1, 3, 18]. In this paper attention is paid to drum mills, shown on fig. 1.

The best choice for grinding bodies (balls) is chromed steel. Due to the relatively higher mass and stiffness, the material is grinded quickly and efficiently with a minimal pollution of the final product. In case of grinding of a flammable material it is recommended the use of lead balls.

Fig. 1. Ball mill.

Lead as a material has a very high density. Soft material usually contributes to pollution of the final product. The ceramic balls are preferred when the pollution of the final product should be minimal. Due to their light weight ceramic balls can be used for longer periods. The effective operation of drum mills depends on the character of the movement of the grinding media. At a small angular speed of the mill the filling the entire bulb is exported into the direction of the rotation of the drum (a cascade mode - Fig. 2a). It is used in rod mills and ball mills during the second and subsequent stages of grinding. In a cascade mode the performance is small. Therefore, this mode is rarely applied. With increasing the rotational speed of the mill, part of the balls located in the outermost layers are separated from the drum and begin to move along the parabolic trajectories. The remaining balls work in a cascade mode (mixed mode - Fig. 2b). In a waterfall grinding mode the balls from all walks rise along with the drum, detach from it and pass in free flight. Grinding the material in this mode, known as cataract regime, is done primarily by shock and partly by grinding. This is the most common mode in practice - fig. 2c. When the rotational speed of the mill is equal or greater than the critical, the balls start to move together with the drum. If the mill is in operation with more than the critical speed - Figure 2d and there is an increased wear of the lining of the drum, leading to frequent replacement. When the rotational speed of mill becomes so great that it exceeds the critical and the innermost layer of balls, the entire bulb filler is evenly distributed along the periphery of the drum and begins to move with it. This mode, shown in Fig. 2 e is called flywheel mode. [1]



a) b) c) d) e)

Fig. 2. Movement of grinding bodies. [1]

3 Effect of the shape of the grinding bodies.

The shape of the grinding bodies affects productivity, quality, energy efficiency, reliability and efficiency of the grinding process. It is less studied compared to the influence of the other parameters of the workflow (rotational speed output of the mill, dry or wet grinding) and parameters of the grinding media (size, weight, density). [4, 5, 7, 13]. Grinding bodies with different forms have different surfaces and point contacts with each other and with the milled material. Fig. 3 shows the spherical tetrahedron [6]. In order to establish the behavior of the spherical tetrahedron in the mills is necessary to make the simulation and build a model of the movement.

Studies are made with the most common type of grinding bodies - spheres, analyzing the behavior of the two bodies (sphere and a tetrahedron).

Fig. 3. Spherical tetrahedron.

4 Methodology for studying the movements of a spherical tetrahedron.

In order to study the behavior of the spherical tetrahedron by movement in the laboratory it is used a mill simulation software environment, created with the EDEM Software. The technical realization of the method is the following sequence:

1. Determining of the size of the laboratory mill.
2. Determining the size of the spherical tetrahedron.
3. For the realization of the simulation parameters are set: gravity, materials and interaction between the tetrahedron and laboratory ball mill.
4. Making 3D model of the spherical tetrahedron.
5. Making 3D model of the laboratory mill.
6. Setting the parameter values: direction of the rotation, RPMs of the laboratory mill, percentage filling with spherical tetrahedrons in the laboratory mill
7. Determining of the "contact patch" between the spherical tetrahedron and the inner surface of the mill.
8. Determining the angle of separation vector contact.
9. Determination of angle of incidence of the spherical tetrahedron: falling on the surface of the mill, falling on lifters, falling on another grinding body.

5 Simulation of the movement of spherical tetrahedron.

Simulation of the laboratory mill is realized in a laboratory, created in the frames of the project AComIn, the so called ”SmartLab”, at the Institute of Information and Communication Technologies, BAS, using a software product EDEM Software. The dimensions of the laboratory mill are: internal diameter D = 305mm, length L = 305mm and number of 12 lifters - Fig. 4. On the basis of the laboratory mill is built a 3D CAD model. This model is used for the simulation modeling - Fig. 5.

Fig. 4. Common view of the laboratory mill.

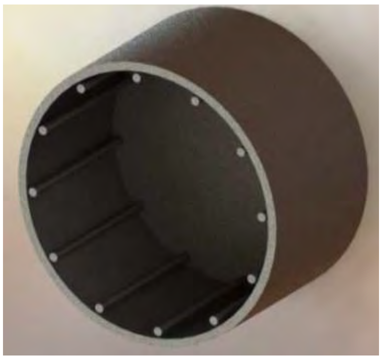


Fig. 5. 3D CAD model of the laboratory mill.

The spherical tetrahedron has a diameter corresponding to the size of 25 mm of the known spherical grinding bodies. EDEM Software works with spheres. For the construction of the grinding body it is necessary to create a 3D model of a spherical tetrahedron (Fig. 6). The next step, after the construction of the model is importing a "mesh" in EDEM Software. To achieve the desired form, the mesh is filled with numerous spheres (Fig. 7).

In references [1] with the filling of the mill grinding bodies are recommended to be in the range of 28 to 32%. The volume V_B, occupied by the grinding media as a percentage of the volume of the mill is:

$$V_B \frac{M_B/\rho_B}{V_M.100} \tag{1}$$

, where M_B and ρ_B are respectively the mass and density of the grinding bodies. The total volume occupied by the load may vary depending on the type of the mill. The one used in this case is 30% (Fig. 8).

Fig. 6. 3D Model of spherical tetrahedron

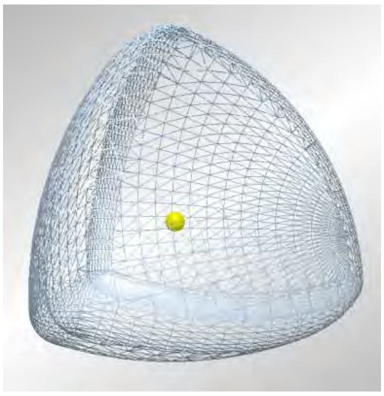


Fig. 7. Mesh of spherical tetrahedron

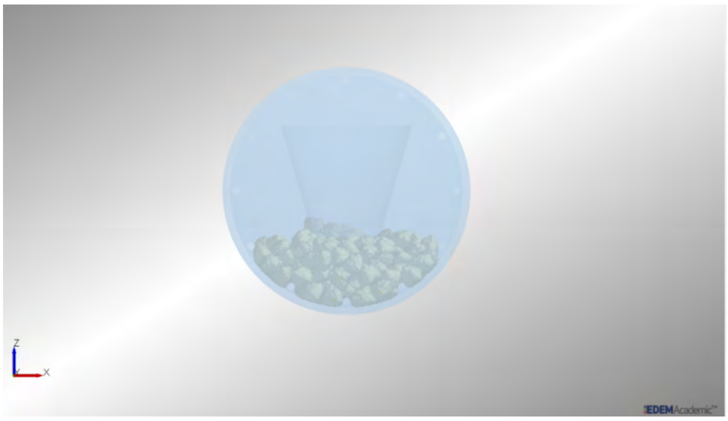


Fig. 8. Filling with 30% of overall load of the laboratory mill.

Under the requirements of [1] mill speed is determined by the formula:

$$V_{cr} = \sqrt{\frac{g}{R}} = \sqrt{\frac{9{,}81}{0{,}1525}} = 8{,}02\,rad/s = 76\,rpm \qquad (2)$$

, where: V_{cr} is the critical rpm of the mill [rad/s or rpm];
g – the gravity [m/s];
R – the inner radius of the drum [m].

The simulation is applied by the Hertz-Mindlin method. This method allows the precise setting of the ration between normal and transverse directions. [8, 9, 10, 11, 12]

The equation for hardness of the particles in normal direction of contact is:

$$K^{n} = \left(\frac{2.(G)\sqrt{2\tilde{R}}}{3(1-(\upsilon))}\right)\sqrt{U^{n}} \qquad (3)$$

, also in transverse direction, the equation of contact is:

$$K^s = \left(\frac{2.(G)^2.3(1-(v)\bar{R}^{1/3})}{2-(v)}\right).|F_i^n|^{1/3} \tag{4}$$

, where: G is an elastic modulus in transverse, v –Poisson ratio, R – radius of particles.

6 Analysis of the obtained results.

Mills in most cases operate at 65% to 85% of the critical speed. For this object of study are used 75% of the critical one, which is 57 rpm. It reaches the most used mode – the cataract mode [1, 2, 3]. The Smart Lab equipment of the IICT BAS – the EDEM Software, is used to determine the angle of separation of the shoulder, angle of incidence and power of stroke. [2, 7]

The angle of separation and the angle of incidence are extremely important for the energy efficiency of the process. By various types of grinding bodies the angle of separation from the shoulder of the mill is variable too. To achieve the optimal angle of separation from the shoulder of the mill, the rpm are calculated by the formula (2). A random body is taken in a random point of time of the simulation. The trajectory of this body is traced. Defined are the angle of separation and angle of incidence of the body. The coordinate "x" is perceived to 0 ° and based on it is defined the angle of separation from the shoulder of the mill, which, in this case it is 208,85 ° (Fig. 9). The angle of incidence is 56,72 ° (Fig. 10).

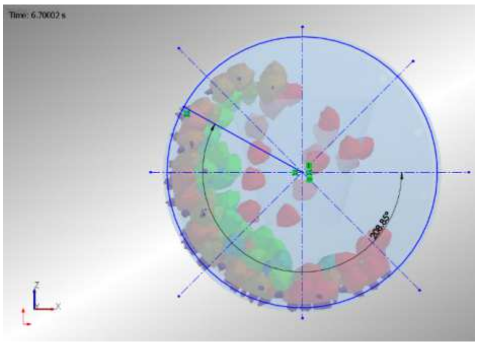


Fig. 9. Fig. 9. Angle of separation

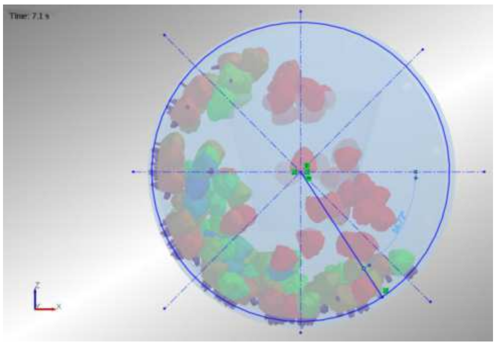


Fig. 10. Angle of incidence

The dependence of the force acting on a given body is to be determined after the determination of the angles. Into consideration is taken the angle of incidence, at the moment, when the body does not fall on the wall of the mill or on lifters and contacts with other bodies. Fig. 11 shows the force that acts on the body during the simulation.

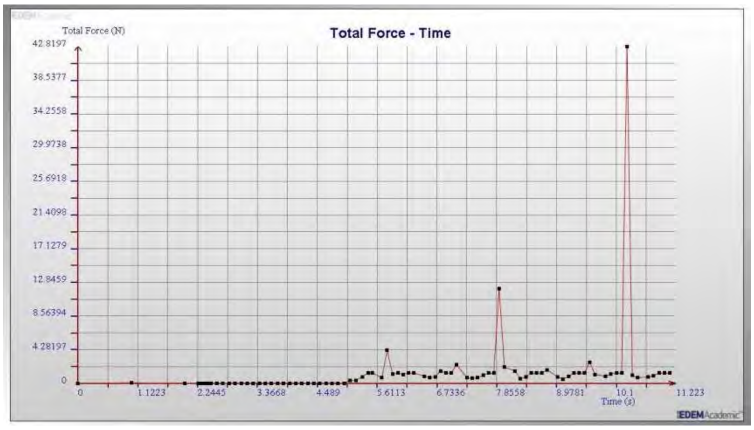


Fig. 11. Force that acts on the body throughout the simulation.

At the peak 1 from the graph, the power obtained in the moment of impact at t = 5,8 s is F = 4,22 N. The contact consists between 3 bodies. At the peak 2, t = 7,9 s, the power is F = 12,03 N and the contact is with other two bodies. At third peak at t = 10,3 s, the power is F = 42,82 N – the contact is with another body.

Conclusion

The process of grinding of current milling machines is examined. Attention is paid to one of the main modes of ball mills and influence of the shape of the grinding bodies. It is set a methodology for studying the spherical tetrahedron. A simulation of the process in both cases of spherical bodies and spherical tetrahedron is obtained.

Factors influencing the angles of separation and incidence are the following:

- Size of grinding bodies;
- Shape of grinding bodies;
- Size of the mill;
- Revolutions per minute for the drum

Depending on the type of material for milling, can be defined the optimum ratio between these four parameters, which will increase the energy efficiency of the process.

The results of the comparison between spherical grinding bodies, the spherical tetrahedrons shows more effective and more economical grinding process for the second type - spherical tetrahedrons

Acknowledgments

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Современные вычисления для енергийно-еффективных смилателных процессов

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Резюме

В докладе описываются изследования смилательных процессов в разных режимах и симуляции и при пользованием разных форм смилательных тел (например сфероидальный тетраедр). Симуляции сделаны при помощи EDEM Software - The discrete elements method. Изследовано влияние форм телах на енергийной ефективности процесса. Определены силы ударов и углах отделении материала в разных случаях.