УДК 621.926.5:539.215

EXPERIMENTAL APPROBATION OF THE MODEL OF THE GRINDING MECHANISM BY COMPRESSION IN A TUMBLING MILL BASED ON DATA VISUALIZATION

С. В. Жабчик
здобувач вищої освіти першого (бакалаврського) рівня, 4 курс,
спеціальність «Галузеве машинобудування»,
навчально-науковий механічний інститут
Науковий керівник – д.т.н., професор Ю. В. Науменко

Національний університет водного господарства та природокористування
м. Рівне, Україна

The grinding process in a tumbling mill with the implementation of the mechanism of destruction by crushing, which is caused by the mechanism of compression filling, is considered. The compressive interaction in the active zone of the lower end of the grain filling chamber of the rotating drum is taken into account. A mathematical model was built based on data visualization. The influence of the rotation speed on the grinding performance was evaluated by experimental simulation.
Keywords: drum mill, intra-chamber filling, compressive loading, crushing failure, grinding performance.

Розглянуто процес подрібнення в барабанному млині при реалізації механізму руйнування роздавлюванням, який спричинено механізмом навантаження стисканням. Враховано стискаючу взаємодію в активній зоні нижнього кінця зернистого завантаження камери обертового барабана. Побудовано математичну модель на основі візуалізації даних. Експериментальним моделюванням оцінено вплив швидкості обертання на продуктивність помелу.
Ключові слова: барабанний млин, внутрішньокамерне завантаження, навантаження стисканням, руйнування роздавлюванням, продуктивність подрібнення.

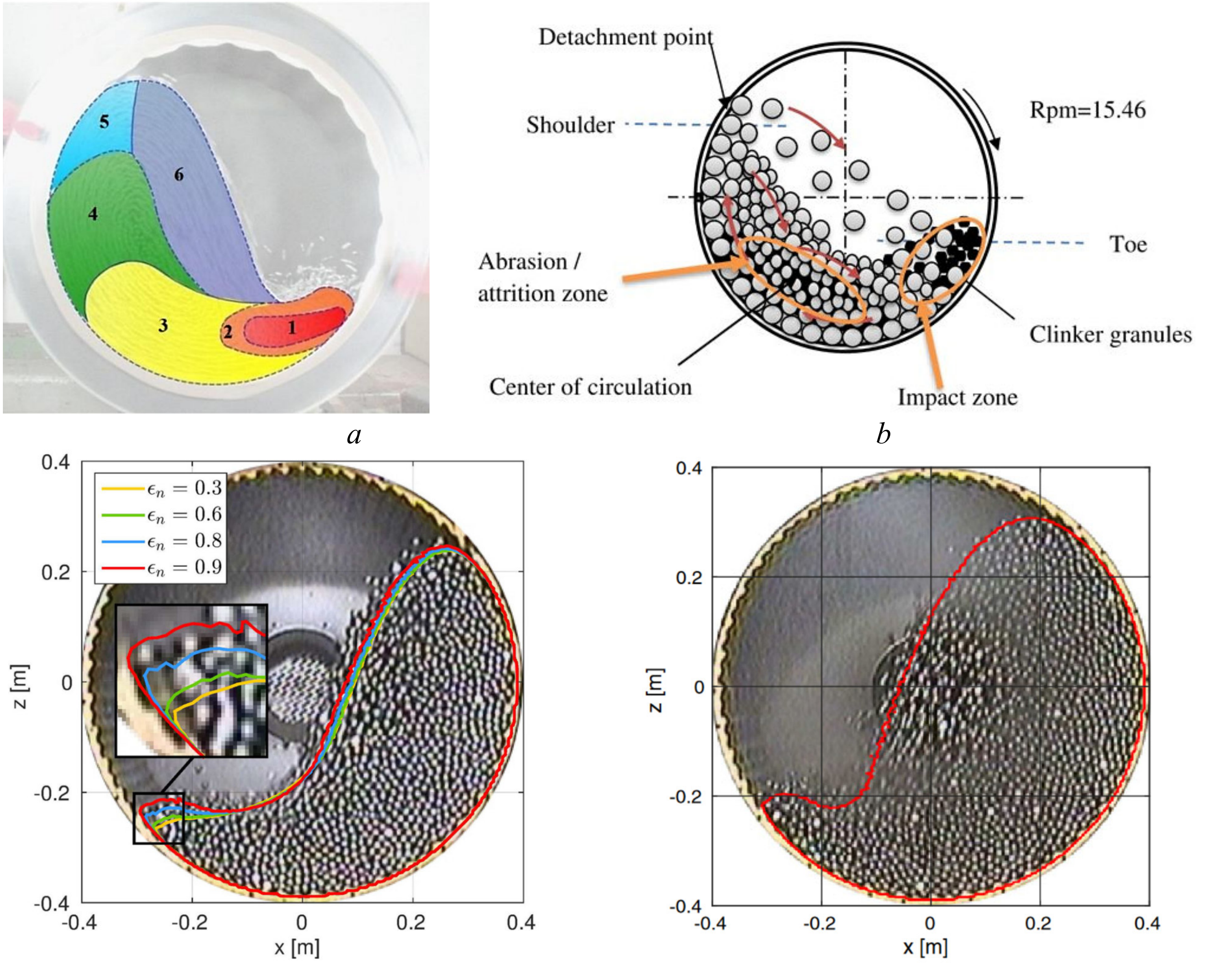
Grinding is a rather energy-intensive technological process. Grinding mineral raw materials and cement clinker consumes 3% of the electricity produced in the world. The high energy intensity of grinding in a tumbling mill is caused by energy dissipation due to the shear circulation of the internal chamber fill. The problem of reducing the energy intensity of the working processes of these mills remains relevant.

The algorithm for implementing the method of analytical-experimental modeling of movement zones of granular filling in the cross-section of the chamber of a rotating drum is given in [1]. Modeling consists in constructing flow patterns by determining the position of the boundary of the transition of the passive zone into the fall zone [2] and the parameters of the shear layer [3].

The geometric and kinematic parameters of the active filling flow zone were studied using the visualization method. In [4], the dynamic parameters of the self-oscillating action of loading and the technological characteristics of grinding for one degree of chamber filling were quantitatively evaluated. The influence of the degree of filling on the efficiency of self-oscillating grinding for one content of particles of the crushed material in the fill is considered in [5]. In [6], the effect of material content on the modes of flow of grinding bodies and the efficiency of self-oscillating grinding for one filling of the chamber was studied. The influence of the simultaneous change in the degree of chamber filling and the content of the crushed material on the grinding process was studied in [7]. However, the obtained results relate only to the case of the self-oscillating mode of flow when implementing the established mechanism [8] of the loss of motion stability [9].

In [10], a mathematical model was built based on data visualization for the grinding mechanism by breaking under the action of the impact loading mechanism.

The most loaded part of filling is the active transition zone of the lower end (Fig. 1, *a*) [11], where intensive destruction of the crushed material occurs. The lower end of filling is considered the zone of impulse interaction (Fig. 1, *b*) [12]. The emergence of the lower end zone is caused by the transition of the shear layer into the solid zone and the implementation of the mechanism of predominantly compressive interaction (Fig. 1, *c*, *d*) [13]. The movement of the liquefied granular fill in this zone has the character of a transient strongly unsteady turbulent flow, which is extremely difficult to model.



a *b* *c* *d*

Fig. 1. The transition zone of the lower end of the filling:
a – scheme of the active zone (1–3) (according to [11]);
b – schemes of the active zone of impulse interaction (according to [12]); *c* – flow pattern in the zone at the degree of chamber filling κ=0.3 and the relative speed of rotation ψ=0.7 for different recovery coefficients of molar bodies ε_n (according to [13]); *d* – flow pattern in the zone at κ=0.4 and ψ=0.8 (according to [13])

At the same time, a significant part of tumbling mills performs medium and fine grinding due to a significant part of the impact on the grinding of the mechanism of destruction by crushing under compressive load. However, determining the parameters of compressive interaction is quite problematic due to the insurmountable difficulties of analytical and numerical modeling and the increased complexity of the hardware analysis of loading behavior. Therefore, the quantitative results of the impact of the compressive action on the productivity of the grinding process remain unknown, which significantly limits the functionality of such equipment.

The purpose of the work is to create a mathematical model of the loading mechanism by the compressive action of the grinding bodies of intra-chamber filling on the particles of the material crushed by crushing in a tumbling mill. The task of the work consists in analytical modeling and setting parameters of the compressive interaction of filling, as well as in experimental modeling and evaluation of the influence of rotation speed on the performance of the crushing grinding process.

An expression was obtained for the analogue of the relative performance of grinding by crushing Q, which corresponds to the relative power of the vertical component forces of the compressive interaction

$$Q = \frac{\omega^2 \left(R^2 - R_s^2\right)^2}{16\pi h^2 Rg} Kn\psi,$$

where ω is the angular speed of rotation of the drum, R is the radius of the drum chamber, R_s is the radial coordinate of the base of the central averaged normal section of the shear layer of the filling chamber, h is the height of the normal section of the filling, g is the gravitational acceleration, K is the mass fraction of the shear layer of filling, n reversibility of filling flow, which determines the number of periods of its circulation in the chamber during one rotation of the drum, ψ is the relative angular speed of rotation of the drum chamber.

Using the method of physical data visualization, pictures of the steady flow of filling in the chamber of a stationary rotating drum at κ=0.45 were obtained [10].

The graph of the analogue of the relative productivity of grinding by compression Q versus the relative speed of rotation ψ is shown in Fig. 2.

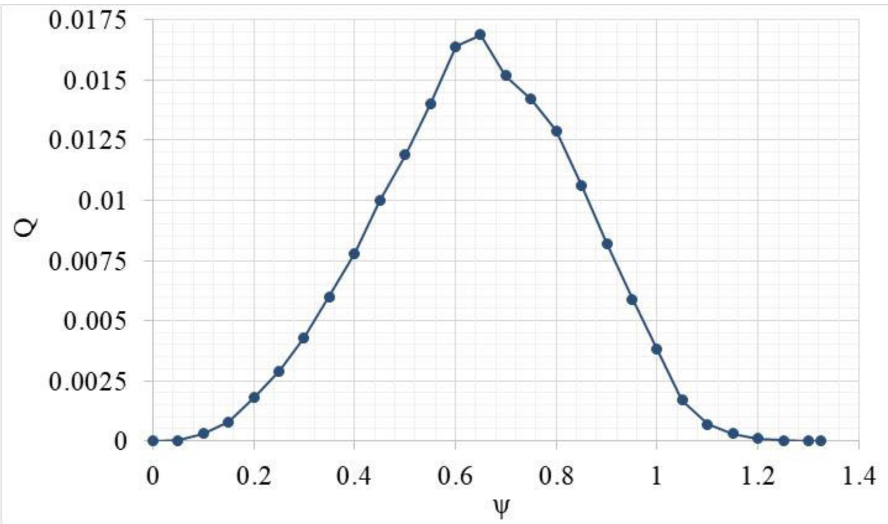


Fig. 2. Experimental dependence of the change in the analogue of the relative productivity of crushing by compression Q on the relative speed of rotation ψ

Analysis of fig. 2 proves that ψ=0.55–0.65 can be considered a rational range of rotation speed values for grinding in a tumbling mill with a compressive action. At the same time, the value of the productivity of grinding by compression Q acquires a fraction of 0.83–0.92 and more, from the maximum possible values.

The results obtained in the work regarding the rational range of rotation speed ψ=0.55–0.65 coincide well with the data [14–16], as well as [17; 18]. In these sources, the processes of medium grinding in tumbling mills were considered, mainly by compression during the compressive interaction of filling elements. In [14; 15] it was experimentally shown that the lowest energy consumption of dry grinding of cement clinker, limestone and quartz in a ball mill is achieved at ψ=0.55. In [15], the rotation speed ψ=0.5–0.6, which is rational for reducing the energy consumption of the process of wet grinding of limestone, was established experimentally. In [16] it was experimentally shown that the highest productivity of wet grinding of iron ore in a laboratory ball mill is achieved at ψ=0.6. Technical standards [17; 18] regulate the processes of wet grinding of ore and non-ore minerals in tumbling mills. According to [17; 18], the nominal rotation speed of rod tumbling mills with peripheral unloading is ψ=0.55–0.65.

The difference between the rational values of the rotation speed for grinding in a tumbling mill by compression with compressive interaction of filling and crushing by breaking with impact interaction was found. The comparative analysis concerned the results of this work and the article [10], which were obtained for the same conditions of experimental modeling. It turned out that the efficiency of crushing by compressive action is achieved at a lower speed of ψ=0.55–0.65, and crushing by impact action – at a higher speed of ψ=0.75–0.9.

Thus, the modeling of the compressive action of the intra-chamber filling of the tumbling mill is based on taking into account the final change in the velocity of the shear layer on the surface of the impulse contact. The inelastic compressive interaction occurs in the active zone of the lower end of the filling chamber at the border of the transition of the shear layer into the solid-state zone. The compressive factor is the average value of the speed of flow in the central averaged normal section of the shear layer. As an analogue of the relative productivity of the compression grinding process, the relative strength of the forces of compressive action can be taken. An analogue of the productivity of grinding by compression reaches its maximum value at the value of the relative speed of rotation ψ=0.65. The mass fraction of the filling shear layer zone attains its maximum value at ψ=0.4–0.45.

1. Naumenko Yu. Modeling of flow pattern of the granular fill in the cross section of a rotating chamber. *Eastern-European Journal of Enterprise Technologies*. 2017. Vol. 5. Issue 1(89). P. 59–69. **2.** Naumenko Yu. Modeling of fracture of the quasi solid-body zone of motion of the granular fill in a rotating chamber. *Eastern-European Journal of Enterprise Technologies*. 2017. Vol. 2. Issue 1(86). P. 50–57. **3.** Naumenko Yu., Sivko V. The rotating chamber granular fill shear layer simulation. *Eastern-European Journal of Enterprise Technologies*. 2017. Vol. 4. Issue 7(88). P. 57–64. **4.** Deineka K., Naumenko Yu. Revealing the effect of decreased energy intensity of grinding in a tumbling mill during self-excitation of auto-oscillations of the intrachamber fill. *Eastern-European Journal of Enterprise Technologies*. 2019. Vol. 1. Issue 1(97). P. 6–15. **5.** Deineka K., Naumenko Yu. Establishing the effect of a decrease in power intensity of self-oscillation grinding in a tumbling mill with decrease of intrachamber fill. *Eastern-European Journal of Enterprise Technologies*. 2019. Vol. 7. Issue 6(102). P. 43–52. **6.** Deineka K., Naumenko Yu. Establishing the effect of decreased power intensity of self-oscillatory grinding in a tumbling mill when the crushed material content in the intra-chamber fill is reduced. *Eastern-European Journal of Enterprise Technologies*. 2020. Vol. 4. Issue 1(106). P. 39–48. **7.** Deineka K., Naumenko Yu. Establishing the effect of a simultaneous redaction in the filling load inside a chamber and in the content of the crushed material on the energy intensity of self-oscillatory grinding in a tumbling mill. *Eastern-European Journal of Enterprise Technologies*. 2021. Vol. 1. Issue 1(109). P. 77–87. **8.** Deineka K., Naumenko Yu. Revealing the mechanism of stability loss of a two-fraction granular flow in a rotating drum. *Eastern-European Journal of Enterprise Technologies*. 2022. Vol. 4. Issue 1(118). P. 34–46. **9.** Deineka K. Yu., Naumenko Yu. V. The tumbling mill rotation stability. *Naukovyi Visnyk Nationalnoho Hirnychoho Universytetu*. 2018. Issue 1(163). P. 60–68. **10.** Naumenko Yu., Deineka K. Building a model of the impact grinding mechanism in a tumbling mill based on data visualization. *Eastern-European Journal of Enterprise Technologies*. 2023. Vol. 3. Issue 7(123). P. 65–73. **11.** Malyarov P., Dolgov O., Kovalev P. Mineral raw material disintegration mechanisms in ball mills and distribution of grinding energy between sequential stages. *Mining of Mineral Deposits*. 2020. Vol. 14. Issue 2. P. 25–33. **12.** Azooz K. Improving productivity based on the movement of materials inside a grinding cement mill. *Kufa Journal of Engineering*. 2021. Vol. 10. Issue 4. P. 1–15. **13.** Boemer D., Ponthot J. P. DEM modeling of ball mills with experimental validation: influence of contact parameters on charge motion and power draw. *Computational Particle Mechanics*. 2017. Vol. 4. P. 53–67. **14.** Gupta V. K. Energy absorption and specific breakage rate of particles under different operating conditions in dry ball milling. *Powder Technology*. 2020. Vol. 361. P. 827–835. **15.** Gupta V. K., Sharma S. Analysis of ball mill grinding operation using mill power specific kinetic parameters. *Advanced powder technology*. 2014. Vol. 25. Issue 2. P. 625–634. **16.** Hanumanthappa H., Vardhan H., Mandela G. R., Kaza M., Sah R., Shanmugam B. K. A comparative study on a newly designed ball mill and the conventional ball mill performance with respect to the particle size distribution and recirculating load at the discharge end. *Minerals Engineering*. 2020. Vol. 145. P. 106091. **17.** *International Organization for Standardization*. Coal preparation plant – Principles and conventions for flowsheets. 2021. (ISO/IEC Standard No. 924:1989). **18.** *Deutsches Institut für Normung*. Maschinen für die mechanische Aufbereitung von Mineralien und ähnlichen festen Stoffen – Sicherheit – Teil 3: Spezifische Anforderungen für Brecher und Mühlen. 2021. (DIN EN Standard No. 1009–3:2020).