GOSPODARKA SUROWCAMI MINERALNYMI

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The influence of chosen ore properties on efficiency of HPGR-based grinding circuits

Introduction

Comminuting circuits constitute an integral part of mineral processing technology and a basis of ore enrichment process. The work efficiency of ore pretreatment circuits for downstream upgrading processes determines in fact the effectiveness of the overall process because it enables proper liberation of useful minerals from the feed to take part. It is especially significant in base metals and non-ferrous ore processing, where liberation of useful components is achieved by obtaining the comminution ratio, suitable for a given type of ore, together with avoiding feed overgrinding, which increases the paymetal losses (Saramak et al. 2010; Tumidajski 2010). Two key issues should be taken into consideration in order to make the circuit effective from the technological and economic point of view, i.e. feed characteristics and proper selection of crushing devices together with the main parameters of the process. The leading role here is played by the type of feed, since its physico-mechanical properties determine the run of the entire comminution process. The technological circuit should be then adjusted to the feed/ore properties. Crushing devices, in turn, are significant, when technological effectiveness (measured by the product particle size distribution) and the economic one (determined by the energy consumption of a single device or the entire circuit) are taken into account.

The most effective comminution process, in the range of physico-chemicals feed properties, takes part when the feed material is exposed to a gradual pressure, which is slowly (not rapidly) increased. In such conditions the disintegration of the rock structure of feed

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takes place at first. As a result of further increasing of the pressing force, the material is gradually compressed, and breaking of coarser particles within their structures occurs, and in the final stage (at the highest value of pressing force), the so-called phenomenon of the micro-crack formations (Reese 2000) within the particle structures can be observed (Fig. 1). In a such course of the comminution process, a significant destabilization of the feed structure takes place, yet the over-grinding phenomenon as well as a generation of undesirable particle fraction –0.063 mm is not observed. Additionally, the energy losses are reduced at the significant reduction of noise, dust and warm emissions.

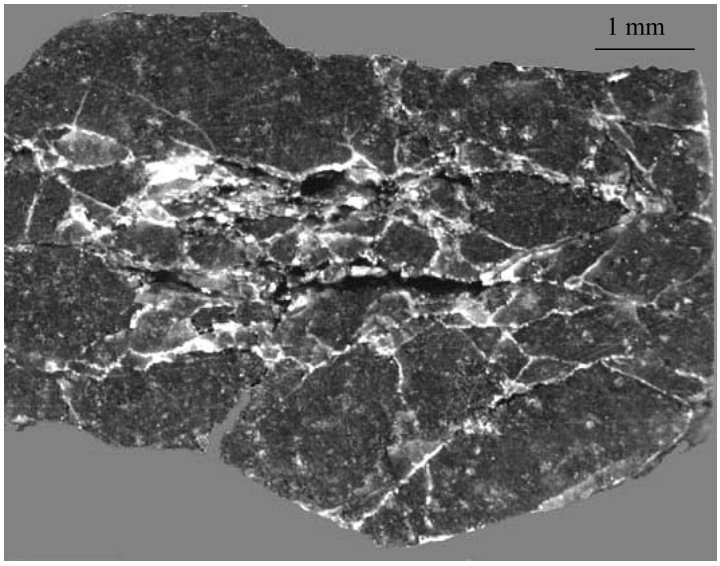

Fig. 1. Micro-cracks in a particle after passing through HPGR

Rys. 1. Mikropęknięcia widoczne w materiale po przejściu przez komorę roboczą prasy walcowej (foldery reklamowe Koeppern: www.koeppern.com)

The grinding manner, described above, is characteristic for the high-pressure grinding rolls (HPGR) devices, then the application of these machines in comminution circuits is a key issue for the mineral enrichment processes. HPGRs have been present in industrial circuits of cement production (Kurdowski 1998) and in hard ore processing technology (Schoenert 1988) since the mid-nineties and the development in HPGR applications in ore pretreatment technology is a current worldwide trend. At present, there are not many publications in Poland concerning the HPGR technology; additional information can be found in the papers by Gawenda 2009; Naziemiec, Saramak 2009; Saramak 2011. The investigations of grinding processes in HPGR devices are still in progress and the technical level of current industrial presses was obtained at the beginning of this century (Morley 2003). The HPGR technology is currently the most effective method, as far as energy consumption and hard minerals comminution are concerned and can be a good alternative for SAG and even tower mills (Kalinowski 2006).

The feed for HPGR-based crushing circuits can be analyzed with regard to its physico--mechanical properties, mineralogical composition, particle size distribution and other features which determine the effect of comminution process, assessed by the quality of grinding products, process energy consumption, process capacity and economic indices. It is also worth mentioning here that the material containing the exceeding amount of clay and loamy components is not a suitable HPGR feed, since both the reduction ratio for the press and the entire circuit and the capacity indices are significantly lower. Roller presses are also sensitive to the over-sized particles in the feed. The maximum particle size, according to various investigations, should not be larger than the width of a working gap; the working gap, in turn, should be adjusted at the level of 2–2.5% of the roller's diameter (Morley 2003; Naziemiec, Saramak 2009). From the above information it results that the maximum HPGR feed particle size is strictly connected with the HPGR size and the following relationship can be written:

$$d_{\max} \leq 0.025D \tag{1}$$

where:

D – roll diameter,
$d_{\max}$ – maximum feed particle size.

1. Experimental programme

The experimental programme was divided into three parts encompassing:

— investigations of the feed particle size distribution influence on the process efficiency,
— investigations of the feed moisture impact on the process productivity,
— investigations of a diverse content of finer particles in feed on the technological and economic effects.

The first part was based on the pilot test results for kimberlite (Maxton et. al 2003). Four grinding tests of –40 mm feed material were performed, where in consecutive experiments size fractions –6 mm, –12 mm and –18 mm were removed from the feed.

Crushing tests in parts 2 and 3 were performed in the laboratory HPGR with roll diameter D = 200 mm. All tests were run for fixed values of operating pressure and speed of rolls but the feed samples had diverse moisture content and particle size distribution. Three crushing experiments were carried out in the second part of investigation programme, including the feed with natural moisture content (close to 0%), 2% and 4% of moisture at constant values of all other feed characteristics. Tests were performed for two values of the operating pressure. The third part of the experiment encompassed the investigation of the influence of diverse contents of finest particles in the feed on crushing effects and the process economic efficacy, measured by its energy consumption and capacity. The first sample with a standard content of finest particles, the second, with an increased content of fines, and the last one, devoid

of fines (removed fines constituted around 20% of the sample weight), were prepared (Fig. 3). Experimental results are presented in the section 2.

2. Experimental results

2.1. Particle size distribution vs. comminution effects

Comminution results were presented in the Fig. 2. Respectively, it can be noticed that the removal of 0–6 mm particle fraction from the feed resulted in decreasing of the circuit capacity Q for 20%. A further feed truncation caused a relatively smaller decrease in capacity.

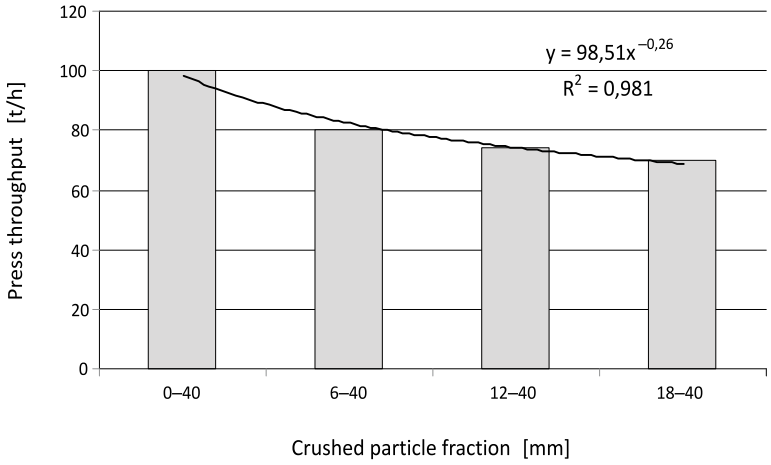

Fig. 2. Relationship between particle size distribution and the press throughput

Rys. 2. Zależność pomiędzy składem ziarnowym nadawy a wydajnością prasy walcowej

It is also possible to determine a relationship between the HPGR throughput and the feed particle size distribution (a capacity model) on the basis of the obtained results. The phenomenon described is well characterized through a hyperbolic function, which can be written as follow:

$$Q = \frac{Q_0}{\left(\frac{d_{\max} - d_x}{d_{\max}}\right)^A} \tag{2}$$

where:

Q – throughput for truncated feed comminution,

Q_0 – throughput for the untruncated feed comminution,

d_{max} – HPGR feed maximum particle size,
d_x – truncation level (all particles below that size are removed from feed),
A – parameter.

Some problems might arise when the feed particle size distribution is unknown. However, it is possible to assume the feed average size distribution for the following reasons:

— roller presses usually work at the second (or third) crushing stage in the circuit, the HPGR feed therefore is a product of the upstream crushing process (or processes),
— cone or gyratory crushers, and less frequently jaw crushers, usually operate at the first crushing stage. An average particle size distribution of product obtained from the above crushers for given operating parameters, can be then accepted (on a certain level of assumption and with a small error).

What is more, the crusher operating parameters at the industrial scale are generally rarely modified and the production then takes place in fixed conditions. Figure 3 presents typical particle size distributions of HPGR feed, determined on the basis of the data from several dozens of pilot scale experiments.

Inspecting Fig. 3 it can be noticed that the HPGR feed in industrial circuits usually contains a balanced share of fine, average and coarse particles (lower, brighter curves in Fig. 3), the feed with higher content of finer particles (five upper darker curves) is rare. The HPGR feed in industrial circuits is then quite unified, considering the particle size, which is obtained through a suitable selection of a respective crusher at the first crushing stage.

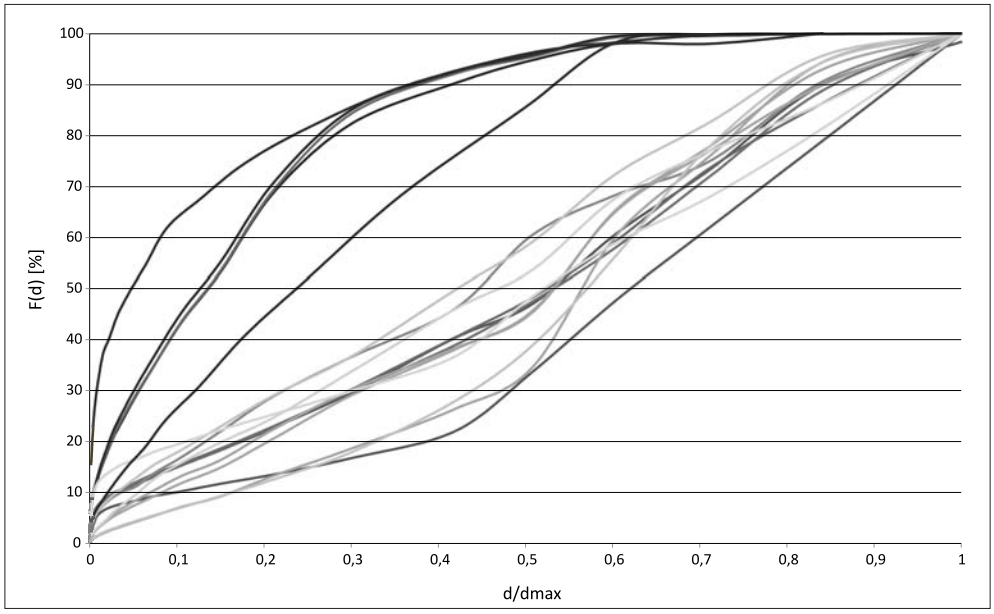

Fig. 3. Typical HPGR feed particle size distribution

Rys. 3. Typowy skład ziarnowy nadawy do prasy walcowej

It results in more predictability of comminution effects obtained at the second crushing stage which enables the respective crushing models to be worked out. The changeability of feed physico-mechanical parameters is also limited due to the HPGR choke feeding system.

The above results of investigations unequivocally point out that the particle size distribution of the feed material significantly influences the process capacity. Comminution effects may also vary for the feed materials with similar d_{max} value, depending on whether a domination of coarse or fine particles takes place, or the feed is devoid of finest particle fractions. In order to investigate that, samples with a diverse particle size composition (Fig. 4) were prepared. They were then crushed in a roller press for identical values of operating pressure and speed of rolls. The first sample had a lower content of finer fractions ("coarse grained" sample), the second one contained an increased amount of finer particles ("fine grained" sample) and finally the third one was devoid of the finest fractions in about 20% of the sample weight ("truncated" sample).

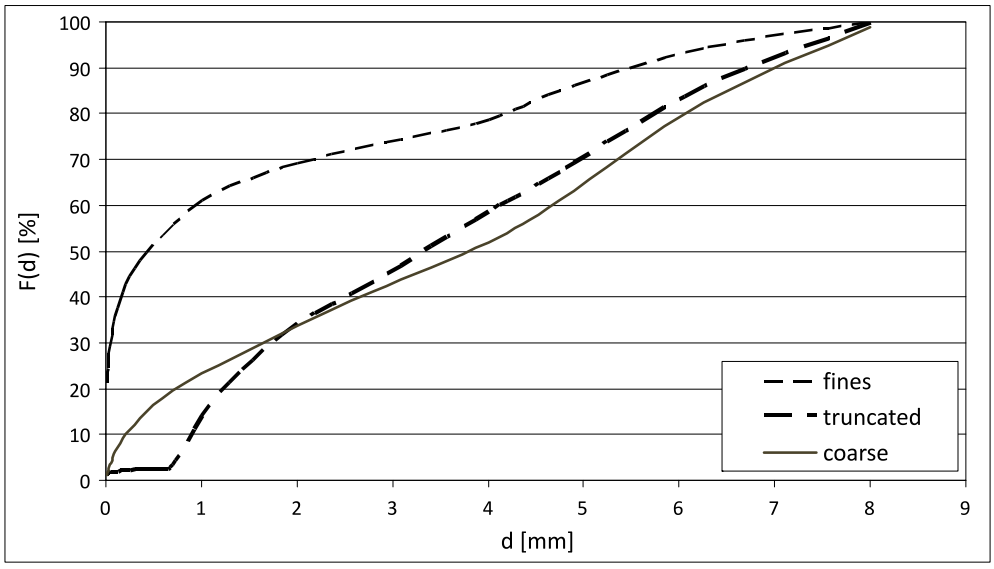

Fig. 4. Feed samples for investigations of particle size distribution on grinding effects

Rys. 4. Nadawa do badań wpływu składu ziarnowego na efekty rozdrabniania

The crushing results are presented in Table 1. Net weight recoveries of products were calculated by subtracting the weight recovery of the individual fraction (below 0.07mm or below 3 mm) in the feed from the weight recovery of the respective product fraction.

It is easy to notice that, in general, the increased content of the finest particles in the feed results in decreasing the S_{50} and S_{80} comminution ratios, due to the fact that fine feed material may act as a cushion absorbing the rolls pressing force exerted onto the material bed in the HPGR crushing zone. A lower content of finest particles, in turn, is effective in obtaining a somewhat more favourable comminution effects, but the most profitable results were obtained for the truncated feed material.

TABLE 1

Results of crushing the material with different particle size compositions

TABELA 1

Wyniki rozdrabniania materiału o zróżnicowanym składzie ziarnowym

	Coarse sample	Fine sample	Truncated sample
S_{50}	5.35	2.44	6.84
S_{80}	5.80	5.07	13.03
Net weight recovery of product –0.07 mm	13.80	4.86	12.58
Net weight recovery of product –3 mm	22.57	29.03	71.29
Weight recovery of product –3 mm	79.40	49.62	77.90
Energy consumption [kWh/Mg]	0.53	0.97	1.81
Throughput [Mg/h]	23.9	42.1	17.6

Apart from comminution ratios S_{50} and S_{80}, the net weight recoveries for particle fractions below 0.07 mm and below 3 mm, as well as the content of below 3mm fraction, were determined in each crushing product. For the copper ore analyzed, the weight recovery of –0.07 mm fraction is essential, because this material is the most desirable feed for the downstream flotation processes, which can be bypassed directly to flotation operations. An excessively long circulation of this fraction in the grinding circuit causes its over-grinding below the lower flotability size limit, and, simultaneously, it results in increasing the pay-metal loses. The process unit energy consumption is increased as well, due to the circulation of the increased mass of the material in the grinding circuit. A generation of –0.07 mm fraction is the most favourable one for the coarse sample and slightly lower for the truncated one. For the truncated material the most effective comminution of the coarsest particles can be also observable.

The analysis of the process energy-consumption points at more favourable effects obtained for the coarse sample; in turn the truncated sample shows the worst results in the issue. The increased energy consumption also results in the decreased throughput – a drop by about 25%, as compared to the coarse sample.

2.2. The feed moisture influence on the process effectiveness

Apart from the particle size distribution, the feed material moisture content is the second value determining comminution effects. The following statement concerning the relationship between the feed moisture and the HPGR crushing process can be written on the basis of performed investigations:

— excessive feed moisture causes the material slip on rolls, decreasing the press throughput,

— excessive feed moisture causes washing out of the material layer from rolls – for studded rolls,
— excessive feed moisture causes increased wear of linings (Morley 2003),
— excessive feed moisture for higher values of operational pressure may increase an entire throughput of the circuit: crusher-HPGR-mill.

The research programme in the issue covered the experiments of olivine and lime crushing according to the scheme presented in Fig. 5.

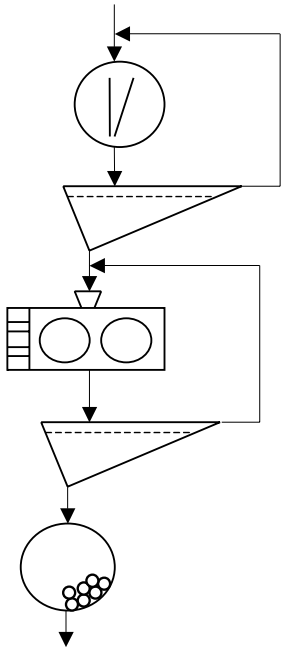

Fig. 5. Experimental crushing circuit for feed moisture investigations

Rys. 5. Doświadczalny układ rozdrabniania dla badania wilgotności nadawy

Figure 6 presents the results of these investigations concerning the circuit capacity. It turns out that for lover values of the operating pressure, the press throughput and circuits capacity is significantly decreased (almost 15%) for the feed moisture exceeding 3%. The more favourable results were obtained for the over twice higher pressure value, because in this case the press throughput increased insignificantly. On the basis of the above results one can state that together with the increase in the press operating pressure the value of feed moisture content and throughput increase. This leads to the improvement of the operating effectiveness of the entire circuit. It should be emphasized, however, that the higher value of operating pressure accepted for the laboratory tests is too high to be applied in circuits in the plant scale. During the process of designing the crushing circuits the lower pressure value (2.3 N/mm^2) should be rather accepted, and on the basis of this value a possible relationship between the feed moisture content and the HPGR throughput should be determined.

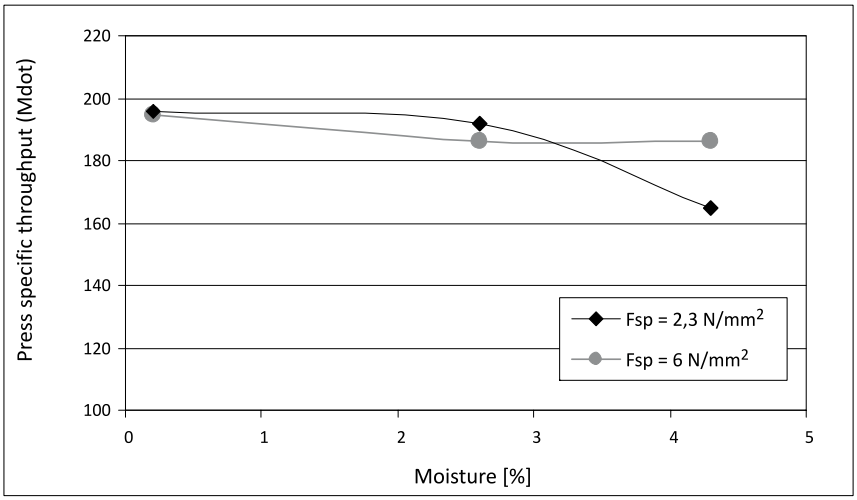

Fig. 6. Relationship between the feed material moisture and press throughput

Rys. 6. Zależność wydajności prasy walcowej od wilgotności materiału

Nevertheless, the information that together with increasing the operating pressure value the influence of moisture content on the press throughput is relatively lower is significant.

Additionally, the relationship between a comminution ratio of the circuit (presented in Fig. 5) and the feed material moisture for both values of the operating pressure was under analysis. The results are presented in Fig. 7.

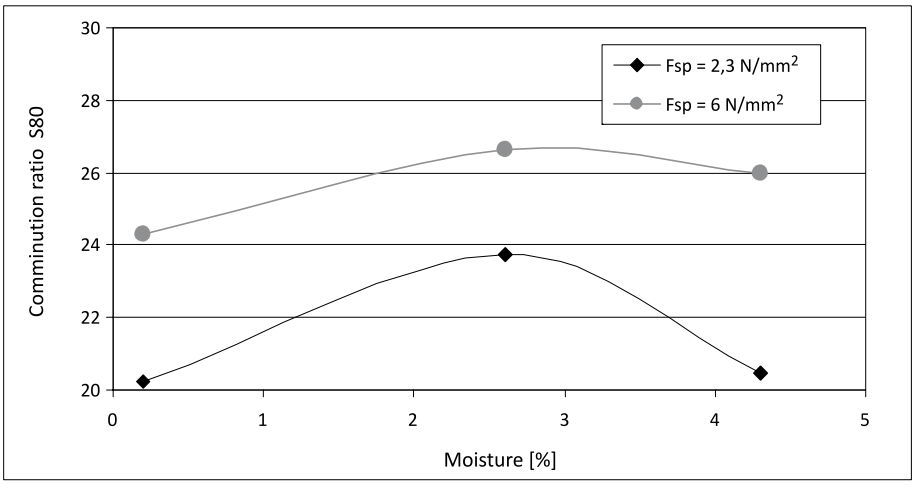

Fig. 7. Relationship between the feed material moisture and comminution ratio S_{80}

Rys. 7. Zależność stopnia rozdrobnienia S_{80} od wilgotności nadawy

The comminution ratio S for the circuit increases initially, then decreases together with the increase of feed material moisture, therefore for a too dry and too wet material lower comminution ratios are obtained. It results from Fig. 7 that for a given type of material the moisture content, which maximizes technological results measured by the comminution degree S, can be selected. For the material under analysis, the optimal moisture content is about 2.5%.

Summary

The feed material properties have a significant influence on the obtained technological and economic effects of grinding processes in High-Pressure Grinding Rolls. A suitable selection of the process run conditions to the material properties permits not only the comminution effect to be maximized, but also enables the rational resource economy to be done, by means of its comprehensive utilization. Comminution of ore with a diverse particle size distribution has its reflection, in turn, in dissimilar technological and economic effects. The most favourable results were obtained for the feed material with the removed finest size fractions (so-called "truncated sample"), while the worst – for the material with increased content of these fractions (fine sample). It can be then profitable to include the HPGR feed pre-screening operation into a technological circuit in order to remove the finest size fractions, during designing the industrial mineral processing circuit. Not only the crushing effects increase (especially for the coarsest size fractions), but also the load of the press will be reduced. The pre-screening undersize can be directed for downstream grinding and classifying operations, bypassing the HPGR, what gives further energy savings.

A special attention should be then paid to the ore physico-mechanical properties, when possible opportunities of HPGR utilization are taken into consideration. The results of the investigation presented in the paper confirm the thesis that, apart from the feed maximum particle size d_{max}, also the weight recoveries of specific particle fractions, especially for finer particles, have a significant influence on the HPGR crushing process. Exact knowledge of the feed particle size distribution enables the circuit, which generates desired comminution results at profitable economic effects, to be designed.

Only chosen characteristics of the feed material, like the particle size distribution and moisture, were investigated in the article. Apart from the above, also the abrasiveness, mineralogical composition, irregular particles content, as well as the bulk density and others, are significant from the point of view of the ore beneficiation process, which will be under investigation in further studies.

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WPŁYW WYBRANYCH PARAMETRÓW RUDY NA EFEKTYWNOŚĆ PROCESU ROZDRABNIANIA W UKŁADACH Z WYSOKOCIŚNIENIOWYMI PRASAMI WALCOWYMI

Słowa kluczowe

Rozdrabnianie surowców mineralnych, wysokociśnieniowe prasy walcowe, optymalizacja procesu rozdrabniania

Streszczenie

Procesy rozdrabniania są podstawowymi procesami przeróbki mechanicznej surowców i jednocześnie są najbardziej energochłonnymi operacjami przemysłowymi w górnictwie. Poprawa ich efektywności czyli odpowiednie rozdrobnienie materiału oraz obniżenie ich energochłonności są bardzo ważne z technologicznego, ekonomicznego oraz ekologicznego punktu widzenia. Przy ustalonych warunkach prowadzenia procesu wzbogacania kluczową rolę odgrywają właściwości fizykomechaniczne nadawy. Odpowiedni dobór technologii wzbogacania do właściwości przerabianego surowca pozwala podnieść efektywność samego procesu, a także prowadzić racjonalną gospodarkę zasobami poprzez ich pełniejsze wykorzystanie.

W artykule przebadano wybrane cechy składu ziarnowego oraz wilgotności nadawy na wyniki rozdrabniania oraz efekty ekonomiczne. W tym celu zrealizowano program badawczy, obejmujący badanie wpływu zróżnicowanego składu ziarnowego nadawy do prasy walcowej na uzyskiwane stopnie rozdrobnienia oraz produkcję wymaganych frakcji ziarnowych produktu. Przebadano także wpływ wilgotności materiału na wydajność oraz efektywność pracy układu rozdrabniania z wysokociśnieniową prasą walcową.

Na podstawie uzyskanych wyników zaproponowany został model wydajnościowy prasy walcowej oraz praktyczne wskazówki dotyczące projektowania układów przemysłowych.

Key words

Raw material comminution, high-pressure grinding Rolls, crushing process optimization

Abstract

Comminution processes are fundamental operations in raw material processing, they are also the most energy-intensive mining processes. The efficiency improvement of crushing processes is a key problem from technological, economic and ecological points of view. Physico-mechanical feed properties play a key role in the process course optimization, at given technological process conditions. A suitable selection of processing technology for determined ore characteristics increases the process efficiency and the raw materials economy through their better utilization.

High-pressure ore comminution processes are practically the most efficient methods of material size reduction. It is a result of the lower process energy-consumption in HPGR and lower energy-consumption of the downstream grinding processes, as compared to conventional crushing devices. The reduction ratio value in downstream upgrading operations is also favourable due to the micro-cracks generation. It appears that the feed particle size distribution during high-pressure comminution is crucial to the obtained technological results.

The experimental programme covered investigations of the influence of different particle size composition of ore on technological and economic results as well as the influence of feed moisture content on the process capacity and comminution effects. Economic results were assessed through the HPGR energy-consumption and throughput indices. The results of investigations presented in the paper confirm the thesis that, apart from the dmax value, proportions of individual particle fraction contents are also significant, especially the contents of finer fractions.

The crushing results of the material with diverse particle compositions are reflected in the obtained different technological and economic effects. Considering the overall effect it is possible to design the most suitable circuit for a given feed. The results of investigations can be then helpful during the process of industrial application of HPGR, either in modernization of an existing circuit, or during the designing of a new flowsheet. The optimal circuit designed on the basis of crushing results should provide maximization of both technological and economic effects.