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ANALYSIS OF EFFICIENCY OF GRINDING IN BALL AND ROD MILLS DEPENDABLY ON CONTENTS OF FINE PARTICLES IN FEED**

1. Introduction

About efficiency of mill work the parameters of work decide, like rotary speed, load, grinding medium contents, sort of grinding medium and its size and parameters of the feed being comminuted what means particle size distribution including maximum size of particle and fine particles contents as well susceptibility on comminution.

The paper contains the analysis of efficiency of ball and rod mills works dependably on particle size distribution of the feed, in particular fine particles contents which may be seemed as ones do not requiring further comminution in certain stage of the process. The authors used to this purpose the results of researching works conducted by AGH for the O/ZWR KGHM PM SA entitled “Analysis of potential use of rod mills in O/ZWR Region Rudna and Lubin dependably on changes of lithology and granulation of the feed” (agreement no. KGHM-ZW-U-0093-2010, year 2010) and “Determination of the influence of the liberation of particle fraction below 5 mm from the feed to the mills on processes of classification and beneficiation in O/ZWR Region Polkowice” (agreement no. KGHM-ZW-U-0018-2011, year 2011). This is related to the comminution system with classification operation before grinding in purpose of eliminating so-called “ready” particles (fine ones).

The results of conducted considerations were presented in the following paper and may be useful during designing grinding systems as well may give clues concerning leading processes of grinding and classification as they can be source of ensuring optimal point of technological efficiency by lowered investments and process costs.

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2. Evaluation of the influence of grinding time and granulation of the feed on comminution effects in rod and ball mills in laboratory scale

2.1. Methodology of investigation

The purpose of the research was to determine the comminution levels and increase of the finest fractions for ore by influence of dry grinding in rod and ball mills in various grinding times according to scheme presented on Figure 1. The investigations concerned the kinetics of grinding process of two representative samples of copper ore taken in O/ZWR Rudna after vibrating screen — lower product was directed on side A and after hammer crusher — product was directed on side B. This separation is the first attempt of ore differentiation considering lithology in industrial scale of O/ZWR. It was assumed that the lower product is the ore of increased share of carbonate fraction.

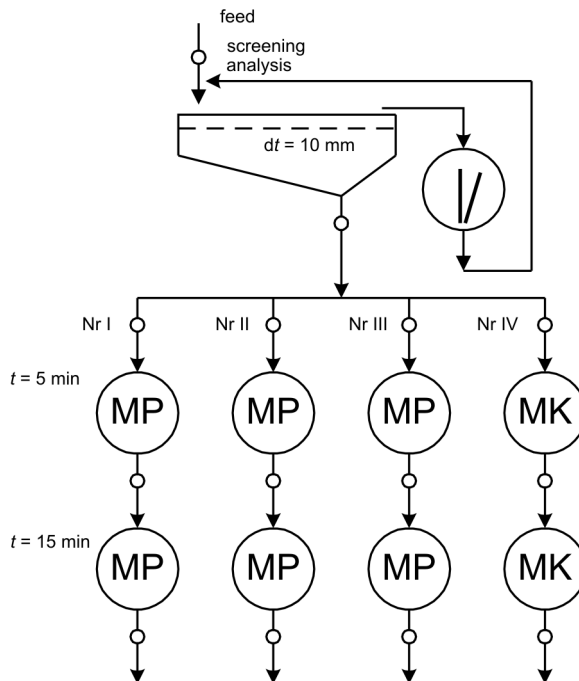


Fig. 1. Ideological technological scheme of conducted laboratory scale investigation

In purpose of preparation of so-called basic feed for laboratory research the particle size distribution was initially determined for samples collected from sides A and B (Fig. 2).

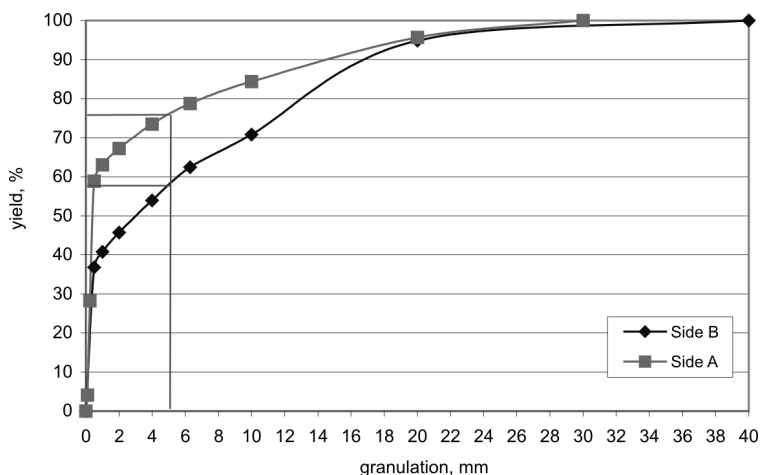


Fig. 2. The particle size curves for the crushing product obtained in Hammer crusher (side B) and fine product from classifier (side A)

The material characterized by granulation from the range 0–30 mm (side A) and 0–40 mm (side B). The particle size distribution curves presented on Figure 2 allowed to determine the yields of fraction below 5 mm which was accepted because of the maximum size of upper product particle obtained in rod mill on side B. Accepting this methodology it is possible to transfer the industrial conditions on laboratory scale in purpose of determination of granulation of the feed which is directed to laboratory mills. So, assuming that industrial scale the ore of granulation 0–40 mm is being directed on side B which after grinding characterizes by maximum size of upper product particle of 5 mm it is also possible to assume that 76% of the material may be non-efficiently grinded what can be proved by the fact that the same number of particles below 5 mm is directed “non-efficiently” to grinding for feed. Going further in this way the feed for grinding in laboratory rod mill can be determined. So as the maximum particle size of the researched feed 10 mm was accepted on the basis of $\frac{1}{2}$ of maximum diameter of the rods used for grinding. So, according to the scheme presented on the Figure 1 the whole material from the delivered sample which was bigger than 10 mm was comminuted in jaw crusher and after averaging the granulation analysis for basic feed (Fig. 3). Then for samples I and IV the lower limit of granulation 0 mm was accepted and for samples II and III the minimum particle size 2 mm was accepted because this value occurred from the graphs (Fig. 3) for particle of 58 and 76 percent. The characteristics of granulation of the prepared samples I–IV was given on graphs (Fig. 4).

The mass of grinding mediums was accepted as constant one 14000 g and the mass of the basic feed (for samples I, III and IV) as 4 times lower, so 3500 g. The mass of sample II was calculated on the basis of the yield of the fraction left on sieve 5 mm in relation to basic feed, i.e. for side B the mass was equal to $42\% \times 3500$ what gave 1470 g. The characteristics of the accepted samples were given in Table 1.

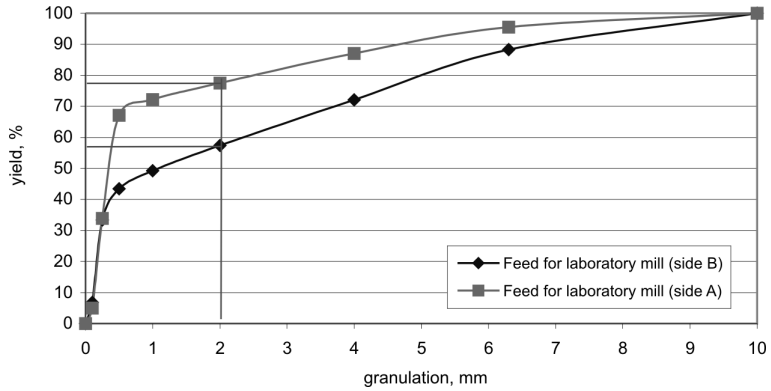


Fig. 3. Basic particle size distribution curves for ore prepared for grinding in laboratory mills (sides A and B)

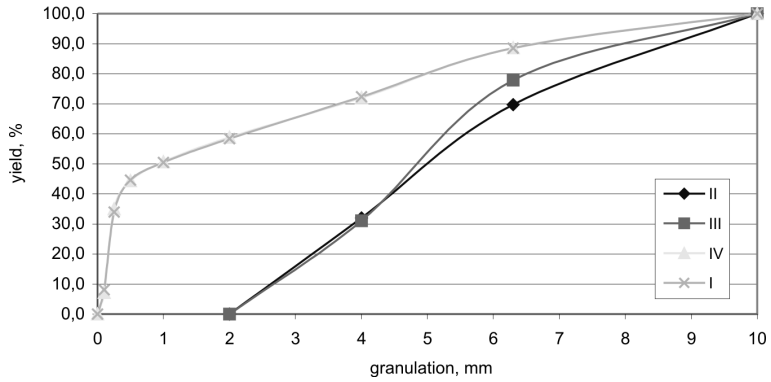


Fig. 4. Particle size distribution curves for ore prepared for grinding in laboratory mills (side B)

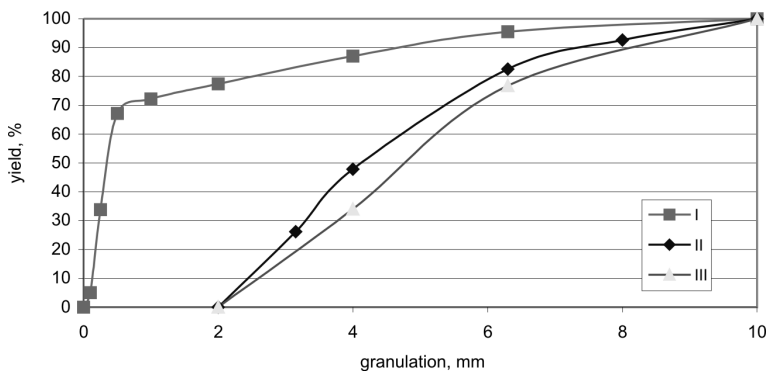


Fig. 5. Particle size distribution curves for ore prepared for grinding in laboratory rod mill (side A)

TABLE 1

Characteristics of samples used for grinding in laboratory conditions

No of sample	Side B				Side A		
	I	II	III	IV	I	II	III
Granulation, [mm]	0–10	2–10	2–10	0–10	0–10	2–10	2–10
Mass of sample, [g]	3500	1470	3500	3500	3500	1470	3500
Sort of mill	MP	MP	MP	MP	MP	MP	MP

The grinding of materials was conducted in the following mills: rod one of the length 440 mm and diameter 300 mm and ball one 305 × 305 mm. The length of rods was 400 mm and the maximum rod and ball diameter was equal to 20 mm. The times of grinding in first series of the investigation was 5 minutes and then the material was additionally grinded in second series during 15 minutes.

2.2. Discussion of results

On the basis of the given products after 5 and 20 minutes of grinding the increases of fine fractions and comminution levels were calculated for ores originated from sides A and B.

The results were presented in Tables 2 and 3 and on Figures 6–11.

Analyzing for side B the process of ore processing after 5 and 20 minutes it is worthy to notice that sample II with granulation 2–10 mm and mass 1470 g was comminuted the most in rod mill giving increase of fine material by 21% in fraction 0–0.071 mm and 93% in fraction 0–1 mm. Also, total comminution level S10 confirms this observations, which was the highest and was equal to 86.7 (Tab. 2).

Similarly, in the case of ore from side A, sample II characterized by the same increase after 20 minutes of grinding in fraction 0–1 mm (92%). Also, the higher increase of this fraction was observed after 5 minutes (18%) in comparison with ore from side B what could be caused by the higher grindability of the ore where sandstone is dominant.

TABLE 2

Comminution levels (side B)

Comminution level	<i>t</i> = 5 min				<i>t</i> = 20 min			
	No. of sample				No. of sample			
	I	II	III	IV	I	II	III	IV
S90	1.3	1.5	1.2	1.0	1.8	34.8	1.6	1.1
S50	4.5	4.3	1.6	4.8	5	35.7	10.9	6.3
S10	1.3	52.0	18.9	1.8	1.7	86.7	24.1	4.8

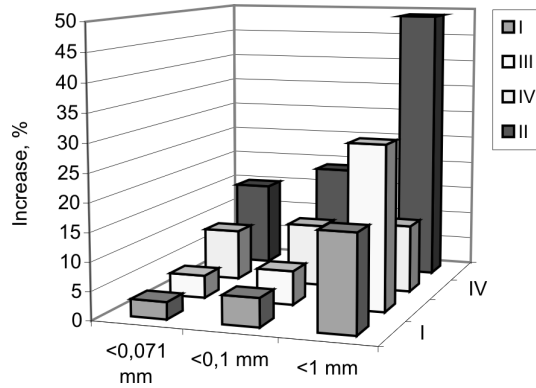


Fig. 6. Percentage increase of fine material in particle fractions dependably on mass and granulation of samples ground during 5 minutes (side B)

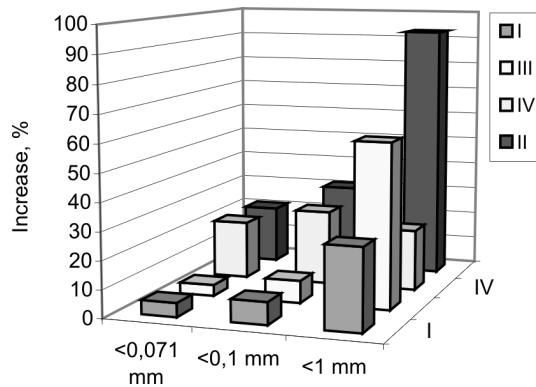


Fig. 7. Percentage increase of fine material in particle fractions dependably on mass and granulation of samples ground during 20 minutes (side B)

TABLE 3
Comminution levels (side A)

Comminution level	<i>t</i> = 5 min			<i>t</i> = 20 min		
	No. of sample			No. of sample		
	I	II	III	I	II	III
S90	2.1	1.4	1.3	9	29.2	1.7
S50	1.9	17.8	2.6	2.1	34.2	21.4
S10	1.9	48	21.7	1.8	96	43.3

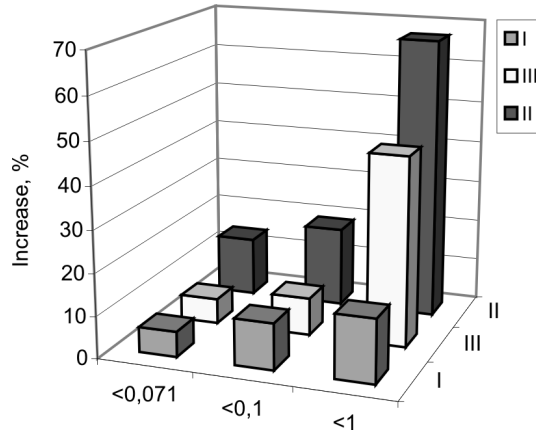


Fig. 8. Percentage increase of fine material in particle fractions dependably on mass and granulation of samples ground during 5 minutes (side A)

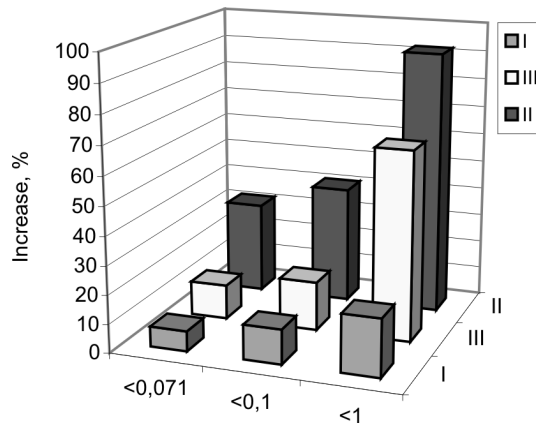


Fig. 9. Percentage increase of fine material in particle fractions dependably on mass and granulation of samples ground during 20 minutes (side A)

High increase of fraction 0–0.071 mm and fraction 0–0.1 mm was characteristic also for material from sample IV (side B, mass 3500 g and granulation 0–10 mm), which was ground in ball mill. However, it is easy to notice that the grinding process is beneficial only for material < 0.1 mm, for thicker particles it is no longer efficient because balls are not able to grind thicker and harder particles. It is also confirmed by total comminution level S90 which was equal only to 1.1 (Tab. 2). For samples from side A the processes were not performed in ball mill.

The smallest increases of fraction 0–0.071 mm and 0–0.1 mm were observed for samples I and III. Comparing the results for side B it occurred that share of increases of these fractions grows only by several percents, exactly by 8% for 20 minutes of grinding of sample III (feed without fine fraction < 2 mm). But, very beneficial increases of fine material were observed for fraction 0–1 mm, twice higher after 5 minutes and 20 minutes of grinding for sample III (59%) comparing to sample I (29%).

Furthermore, the qualified comminution levels for sample III were significantly higher comparing to samples I and IV (Tab. 3).

Sample III from side A characterized by high increase of fraction 0–1 mm after 5 minutes (till 45%) and then after 20 minutes (till 66%).

On Figures 10–13 the values of coefficient K were presented which meant the increase of fine material taking into consideration the mass of ground sample for specified particle fraction obtained after 5 and 20 minutes of grinding.

In case of side B, the processing of sample III characterized by the highest coefficient K for fraction 0–1 mm and the highest values of coefficients for fractions below 0.1 mm were obtained for sample IV (processing in ball mill).

From Figures 10 and 11 it occurred that the efficiency of processing in ball mill is high for short period of grinding time (till 5 minutes) and fine granulated feed. Above 5 minutes of grinding the efficiency lowered above 0.1 mm.

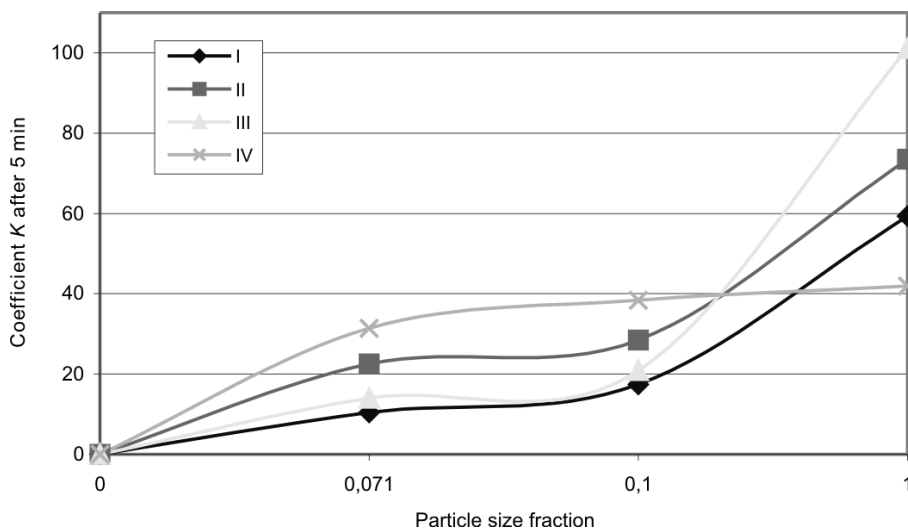


Fig. 10. Dependency between increase of fine material after 5 minutes of grinding considering the mass of sample for certain particle fractions (side B)

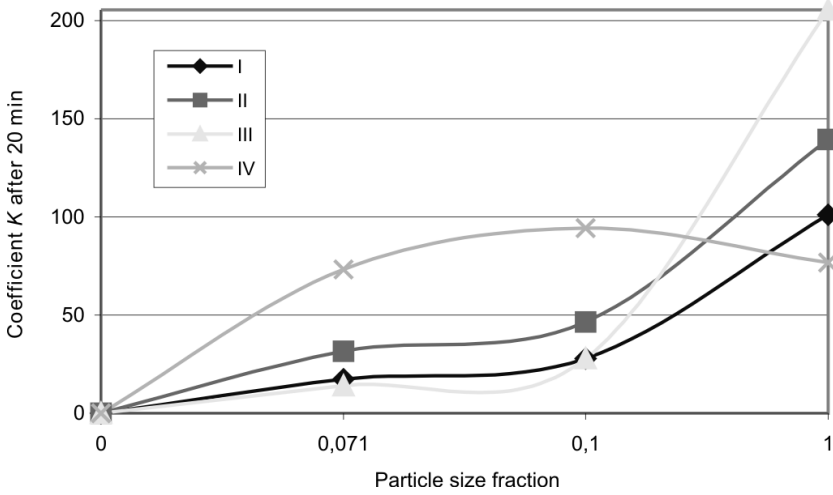


Fig. 11. Dependency between increase of fine material after 20 minutes of grinding considering the mass of sample for certain particle fractions (side B)

Similarly, sample III from side A characterized also by highest value of coefficient K for fraction 0–1 mm for both grinding times — 5 and 20 minutes. The worst effects of processing were obtained for sample I but it was possible to notice that ore from side A is better comminuted than ore from side B (Fig. 12 and 13).

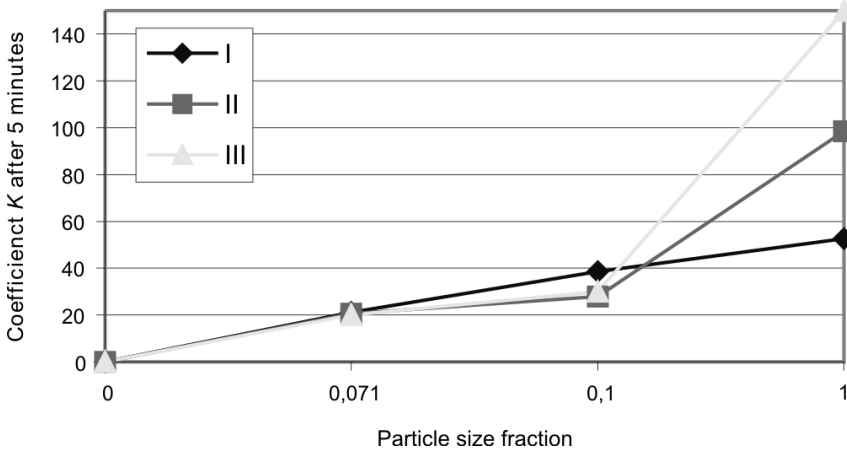


Fig. 12. Dependency between increase of fine material after 5 minutes of grinding considering the mass of sample for certain particle fractions (side A)

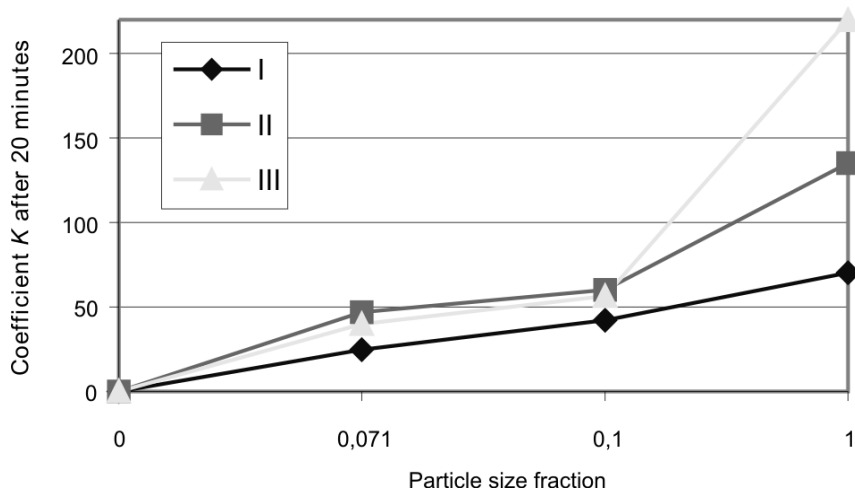


Fig. 13. Dependency between increase of fine material after 20 minutes of grinding considering the mass of sample for certain particle fractions (side A)

2.3. Conclusions from laboratory research

- 1) The best effects of ore comminution (sides A and B) were obtained in rod mill for sample II without fine fraction < 2 mm and twice smaller mass comparing to mass of other samples. It is obvious that the relation of mass of grinders and mass of feed is crucial for the processing effects.
- 2) Taking into consideration the increase of fraction below 0.1 mm after 5 minutes of grinding it occurred that sample I from side A was comminuted the most in such short period of time (coefficient K is equal to 38) what meant that this ore characterized by the highest grindability what was connected with higher sandstone contents.
- 3) The grinding process in ball mill occurred also efficiently, but only for finer particles < 0.1 mm, then stabilized and was not efficient for thicker and harder particles from the feed.
- 4) The worst effects of processing were obtained for sample I (side B) taking into consideration the increases of particles in fractions 0–0.1 mm what confirmed not justified and unnecessary directing together feed with fine fraction. In laboratory conditions as fine fraction the range 0–2 mm was accepted and for industrial ones — fraction 0–5 mm, because such material is obtained from overflow of rod mill being about 58% of yields (for side B). The sample I, which characterized by granulation 0–10 mm and 58% of particles below 2 mm, had the worst results of grinding among all of samples. This was caused by the presence of fine material which was no longer comminuted and created some kind of “pillow” what disturbed the grinding of thicker particles. In laboratory conditions such “pillow” was not so important because high amount of fine and dry

material could be lifted inside of the mill. In industrial conditions such “pillow” occur in form of pulp changing its parameters.

- 5) Considering further processing of samples I and III it is worthy to underline that the thicker material should be directed to rod mill, because for sample III twice higher increase of fraction < 1 mm was obtained comparing with sample I (side B). Comparison of these results with sample II (material without fraction 0–2 mm, but of twice lower mass) indicated that the increase of fine materials was more than three times higher than for sample I.
- 6) On the basis of earlier conclusions it occurred that the most efficient processing in industrial conditions for sides A and B would be obtained the most probably for feed without fine particles and optimally lower mass, but shorter time of grinding what means faster flow of the pulp through rod mill. The finer feed should be then separated and ground in ball mills.

The results of laboratory research gave then valuable information about efficiency of the work of rod and ball mills. From the point of view of industrial process it is important how these results are transferred into work of industrial mills. Applying the results of the work [2] performed for O/ZWR KGHM PM. SA “Determination of the influence of separation of fraction below 5 mm from feed directed to first stage of grinding on processes of classification and beneficiation in O/ZWR Region Polkowice” (agreement no. KGHM-ZW-U-0018-2011, year 2011) the results of ball and rod mills works (with feed after separation of fine fractions) were verified. The subject of research was conducting of investigation concerning determination of the influence of separation of fine fraction from the feed directed to first stage of grinding on classification and beneficiation in O/ZWR Region Polkowice. The realization of work allowed determination the optimal work parameters of the system preparing ore for flotation (size of sieve mesh, processing, sort of grinders in mill of first stage of grinding, nozzles hc500), in which the technological change was done which purpose was to introduce the separation of fine fractions before first stage of grinding.

3. Evaluation of feed granulation influence on comminution effects in ball and rod mills in industrial conditions

3.1. Methodology of investigation

The research work [2] purpose was to evaluate the influence of fine particles selection before grinding on I stage in ball mills on the work of the whole technological system. The paper presented only the results considering efficiency of the mill work on I stage of grinding. The research methodology and its efficiency was wide and contained parameters like change of grinders from balls to rods. This gave interesting results from the point of view of leading process.

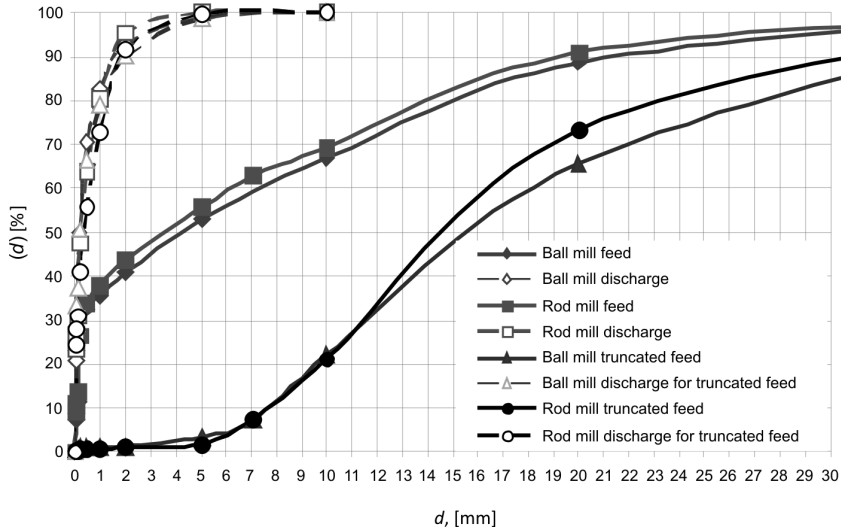


Fig. 15. Particle size distribution functions for feed and mill outflow on 1 stage of grinding for its individual work systems

The analysis of granulation of mill outflow indicates that despite the fact that particles of dimension higher than 5 mm (work system 3 and 4) were directed to the mill, 90% of particles in grinding product is lower than 2 mm. It is significant from the industrial point of view that the processing ability — efficiency of the mill with thick particles is visible. So, the increases of certain particle fractions (0.075 mm and 5 mm) were then analyzed in outflow multiplied by mill production for analyzed mill work systems — Figure 16.

The results indicate that for particle fraction 0–5 mm increase the efficiency was the highest when the mill is filled with rods and the feed is without fine particles. The biggest increase of particle fraction 0–0.075 mm was observed for mill filled with balls and feed with selected fined particles.

The industrial results confirmed the results given by laboratory research and showed that selection of fine particles, i.e. of granulation which can be accepted as comminuted ones on certain stage of the process influenced on better efficiency of comminution in mills. The work of ball mill is more efficient for production of fine particles than the work of rod mill, but this one is more efficient for production of thicker particles. The selection of certain type of the mill must then be conditioned by feed granulation and technological expectations connected with product particle size distribution. For the analyzed maximum size of particle being equal to 40 mm it is good to apply rod mills what is confirmed by theory of mineral processing. The ball mills should be applied for the feed contained maximum particle size below 15 mm or even 10 mm. The correction of grinding efficiency for the feed with selected fine fraction indicated that the achieving high efficiency for classification systems is necessary what would allow lowering the costs of processing.

The introduction of proper systems of fine particles during designing the new schemes of comminution may ensure the lowering of expected device capacity what can low the investment costs and further processing costs connected with energy consumption.

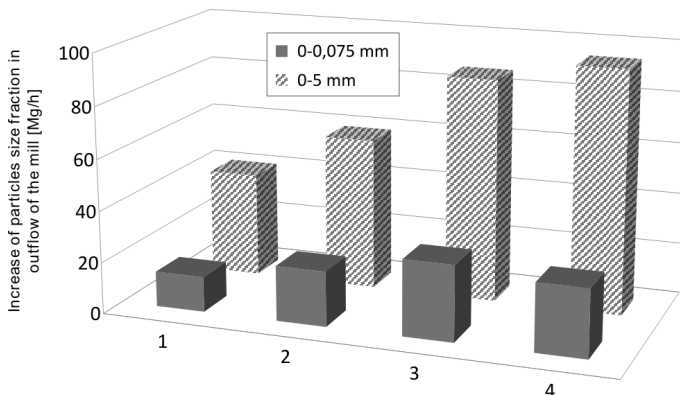


Fig. 16. Increase of particle fraction 0–0.075 mm and 0–5 mm in mill outflow

3.2. Conclusions

- 1) The research over processing effects measured by increase of fine particles in both laboratory and industrial scale were obtained for the feed without fine particles what confirmed unnecessary and not justified direction of the feed with this part of material. In laboratory scale the fraction of granulation 0–2 mm was accepted as the fine one and in industrial scale the fraction 0–5 mm. This was justified by the fact that such granulation is obtained in mill outflow what is about 50% of the feed.
- 2) The investigation results indicated that it is worthy to direct thicker material to the rod mill because it has the biggest ability of increasing the expected particle size fraction in the outflow, i. e. fraction 0–5 mm. The ball mills should be used for fine grinding, i.e. below 0.1 mm.
- 3) In purpose of obtaining the optimal efficiency of comminution the proper analysis of feed granulation and other parameters as grinding time, capacity or density should be performed.

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- [2] Praca badawcza: Określenie wpływu wydzielenia z nadawy do młynów pierwszego mielenia frakcji ziarnowej poniżej 5 mm na procesy klasyfikacji i wzbogacania w O/ZWR Rejon Polkowice (umowa nr KGHM-ZW-U-0018-2011, rok 2011), wykonana przez AGH dla ZWR przez zespół: D. Foszcz — kierownik, K. Trybalski, T. Gawenda, Z. Naziemiec, T. Tumidajski, D. Krawczykowski, R. Ranosz.